

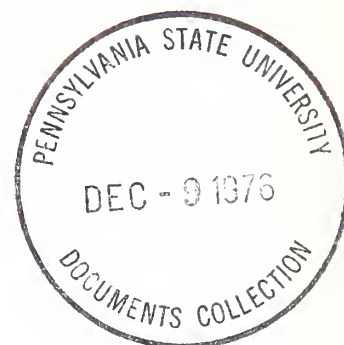
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NOAA Technical Report NESS 75

# Guide For Designing RF Ground Receiving Stations For Tiros-N

Washington, D.C.

December 1976



**U.S. DEPARTMENT OF COMMERCE**  
**National Oceanic and Atmospheric Administration**  
National Environmental Satellite Service

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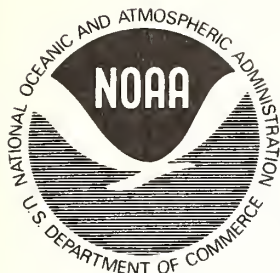
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- NESC 52 Data Reduction Processes for Spinning Flat-Plate Satellite-Borne Radiometers. Torrence H. MacDonald, July 1970, 37 pp. (COM-71-00132)
- NESC 53 Archiving and Climatological Applications of Meteorological Satellite Data. John A. Leese, Arthur L. Booth, and Frederick A. Godshall, July 1970, pp. 1-1--5-8 plus references and appendixes A through D. (COM-71-00076)
- NESC 54 Estimating Cloud Amount and Height From Satellite Infrared Radiation Data. P. Krishna Rao, July 1970, 11 pp. (PB-194-685)

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# **Guide For Designing RF Ground Receiving Stations For Tiros-N**

John R. Schneider

Office of System Engineering

Washington, D.C.

December 1976

**U.S. DEPARTMENT OF COMMERCE**

Elliot L. Richardson, Secretary

**National Oceanic and Atmospheric Administration**

Robert M. White, Administrator

**National Environmental Satellite Service**

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## FOREWORD

This document is intended as a guide to assist a systems engineer in the design of a TIROS-N ground receiving station. The document presents known spacecraft and orbital information, minimum parameters required to define signal thresholds and signal level ranges, a few words on antenna tracking, and examples of the design process. Readers with either minimal or extensive RF experience should find this document useful.

The information contained in this document is believed to be current and accurate as of fall 1976. Some parameters may change slightly up to the TIROS-N launch. However, it is expected that the changes would not affect the results presented. Should the designer have more recent information, he will be able to follow the calculations and apply the appropriate changes.

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## SECTION 1 - INTRODUCTION

### 1.1 General

The evolving requirements of satellite data users and the improved space technology now available have led to the initiation of a third generation polar satellite series. TIROS-N/NOAA, for which the first launch is planned for early 1978, is designed to provide better data than the present polar orbiters. Because of the advanced design, new or modified ground facilities are required to receive, process, and disseminate TIROS-N data to the user community. This document is intended to serve as a guide for designing/modifying a receiving station to be utilized with the TIROS-N/NOAA spacecrafts. Personnel affiliated with the Department of Commerce/NOAA, universities, private industry, and foreign governments should find this document useful for constructing their particular receiving stations.

### 1.2 Document Contents

This document presents the needed spacecraft and orbital information, and the parameters required to receive and demodulate the RF downlinks and to define the data threshold and RF signal range of the receiving system.

Section 2, Mission/Spacecraft Information, describes the goals and objectives of the third generation polar satellite and design parameters of the planned orbit and spacecraft. This background information forms the basis from which the calculations and receiving parameters are derived.

Section 3, S-band/VHF Thresholding Parameters, information is supplied to determine the data threshold and RF signal range expected. The antenna gains, system noise temperatures, and dynamic range of the RF receiving system are derived for all TIROS-N data downlinks. This section applies to the space link and its effect on the receiving station front end.

Section 4, S-band/VHF Receiving Parameters, contains information useful for determining how to configure the receiving system to demodulate all data downlinks. Calculations and results are independent of what has occurred in the space links and apply strictly to receiver/demodulation characteristics.

Section 5, Examples, provides examples for using information contained in the earlier sections. In particular, three types of examples are shown -- the APT only station, the HRPT only station, and an all VHF downlink station.

The document appendices supplement the text and provide the basic calculations used to derive the information in the text. Appendix A contains the link calculations and graphs of antenna gain versus system noise temperature for all downlinks under various elevation angles and threshold margins. Basic calculations are in Appendix B. Appendix C, Antenna Movements, contains a discussion of various antenna mounts and derivations of

of the required velocities and accelerations for those mounts. This appendix is included for information purposes only. References are listed in Appendix D; abbreviations and acronyms are listed in Appendix E.

### 1.3 Document Use

This document is for use by people of various backgrounds. Throughout the text, discussions guide the reader to what is presented, the initial conditions, and how to use the results. The general public, or persons with minimal knowledge of RF ground systems, will find it necessary to read and understand the total document, especially Section 5. A person with RF design experience will find portions of this document useful in his TIROS-N ground system design and will be able to extract his information quickly.

## SECTION 2 - MISSION/SPACECRAFT INFORMATION

### 2.1 General

The goals and objectives of the TIROS-N polar satellite mission and the pertinent parameters of the orbit and spacecraft are stated in this section.

### 2.2 TIROS-N/NOAA Polar System

The National Environmental Satellite Service (NESS) operates a network of satellites and associated ground facilities to provide data used in meeting the National Oceanic and Atmospheric Administration (NOAA) responsibilities in meteorological prediction and warning, oceanographic and hydrologic services and space environment prediction and warning. The evolving requirements of the satellite data users and the improved technology now available have led to the initiation of a third generation polar satellite series. TIROS-N/NOAA, with its first launch planned for 1978, is being designed to provide better data than the present polar satellites. Its major data improvements will be higher accuracy and an increase in the number of atmospheric temperature and water vapor soundings, increased spectral radiometric information for more accurate sea surface temperature mapping and delineation of melting snow and ice fields, a remote platform location and data collection capability, and increased proton, electron, and alpha particle spectral information for improved solar disturbance prediction. The present direct broadcast services will be continued.

This is a NASA and NOAA cooperative program; NASA funds the development and launch of the first flight hardware and procures and launches subsequent space hardware on a reimbursable basis. NOAA funds subsequent flight hardware, establishes the ground facilities, and operates the satellites in orbit. The first NASA-funded satellite of this new series is called TIROS-N. Subsequent NOAA-funded satellites are called NOAA-A, -B, -C, etc., before flight, and will be named NOAA-n+1, -n+2, etc (where n is the number for the last successful ITOS spacecraft) after they are successfully orbited.

#### 2.2.1 Atmospheric Sounding

One of the primary purposes for the new TIROS-N/NOAA satellite system is to improve the accuracy of the temperature soundings, to improve the yield of such soundings, especially in cloudy regions, and to increase the number of levels at which water vapor content determinations are made.

The TIROS Operational Vertical Sounder (TOVS) will provide data for transmission to both the HRPT and beacon data receiving stations. The data will be transmitted in digital format at full instrument resolution and accuracy.

The TOVS consists of three separate and independent subsystems, the data from which may be combined for computation of atmospheric temperature profiles. The three instruments are:

1. The Basic Sounding Unit (BSU)
2. The Stratospheric Sounding Unit (SSU)
3. The Microwave Sounding Unit (MSU).

A fourth instrument is being considered for flight on later spacecraft of this series. This instrument would provide measurements in the 4.3  $\mu\text{m}$  region as well as the 15  $\mu\text{m}$ .

The BSU is designed to provide global infrared radiance data for calculation of 1) temperature profiles from the earth's surface to the 10 mb level in the stratosphere for clear or partially cloudy skies, 2) water vapor content at three levels in the atmosphere, and 3) total ozone content of the atmosphere. To accomplish this, the 14 channels shown in Table 2-1 are used.

Table 2-1.--BSU spectral channels

Central Wave No. ( $\text{cm}^{-1}$ )	Half Power Bandwidth ( $\text{cm}^{-1}$ )	Wavelength ( $\mu\text{m}$ )	NE $\Delta N$ ( $\text{mW}/\text{m}^2\text{-sr}\cdot\text{cm}^{-1}$ )
2700	300	3.70	0.003
2350	50	4.26	0.03
1030	25	9.71	0.20
899	15	11.12	0.15
750	15	13.33	0.20
735	15	13.61	0.20
715	15	13.99	0.20
700	15	14.29	0.20
690	15	14.49	0.25
678	15	14.75	0.25
669	3.5	14.95	0.75
532	25	18.80	0.25
432	25	23.15	0.25
340	25	29.41	0.25

The Instantaneous Field of View (IFOV) of all detectors will be stepped together across the satellite track by use of a rotating mirror. This cross-track scan, combined with the satellite's motion in orbit, will provide coverage of a major fraction of the earth's surface. The essential parameters of the instrument are indicated in Table 2-2.

Table 2-2.-- BSU instrument parameters

<u>Parameter</u>	<u>Value</u>
Calibration	Stable blackbody and space background
Cross-track scan	$\pm 49.5^\circ$ ( $\pm 1127$ km)
Scan time	6.4 sec
Number of steps	56
Step angle	$1.8^\circ$
Step time	100 ms
Ground IFOV at nadir	21.8 km diameter
Ground IFOV at scan end	73.2 km cross track by 37.3 km along-track
Distance between IFOV's	42 km along-track
Data rate	2.88 kbps

The SSU employs a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel are determined by the pressure in a carbon dioxide gas cell in the optical path. The amount of carbon dioxide in the cells determines the height of the weighting function peaks in the atmosphere. SSU characteristics are shown in Tables 2-3 and 2-4.

Table 2-3.--SSU channel characteristics

<u>Channel Number</u>	<u>Central Wave No. (cm<sup>-1</sup>)</u>	<u>Cell Pressure (mb)</u>	<u>Pressure of Weighting Function Peak (mb)</u>
15	668	100	15
16	668	35	5
17	668	10	1.5

Table 2-4.--SSU instrument parameters

<u>Parameter</u>	<u>Value</u>
Calibration	Stable blackbody and space background
Cross-track scan	+40° (+737 km)
Scan time	32 sec
Number of steps	8
Step angle	10°
Step time	4 sec
Ground IFOV at nadir	147 km diameter
Ground IFOV at scan end	244 km cross-track by 186 km along-track
Distance between IFOV's	210 km along-track
Data rate	480 bps

The MSU is a four channel Dicke radiometer making passive measurements in the 5.5 mm oxygen band with characteristics shown in Tables 2-5 and 2-6.

Table 2-5.--MSU channel characteristics

<u>Parameter</u>	<u>Value</u>
Channel frequencies, GHz	50.3, 53.74, 54.96, 57.95
Channel bandwidths, MHz	200
NE $\Delta T$	0.3°K

Table 2-6.--MSU instrument parameters

<u>Parameter</u>	<u>Value</u>
Calibration	Hot reference body and space background each scan cycle
Cross-track scan angle	+47.35°
Scan time	25.6 sec
Number of steps	11
Step angle	9.47°
Step time	1.84 sec
Angular resolution	7.5° (3 dB)
Data rate	320 bps



### 2.2.2 High Resolution Radiometry

One of the TIROS-N goals is to improve upon the present NOAA series Scanning Radiometer (SR) and Very High Resolution Radiometer (VHRR) so that it will be possible to provide more accurate sea surface temperature measurements and improve the ability to differentiate clouds, water, solid snow and ice, and melting snow and ice. This will be accomplished by designing an instrument sensitive to four, and eventually five, spectral channels for the TIROS-N/NOAA satellites.

The Advanced Very High Resolution Radiometer (AVHRR) will provide the data for transmission to both APT and HRPT users. HRPT data will be transmitted at full resolution (1.1 km); APT output will have reduced resolution to maintain allowable bandwidth constraints. The AVHRR for TIROS-N and four or five follow-on spacecraft is a scanning radiometer sensitive in four spectral regions (see Table 2-7). A change in the instrument design which will add a fifth channel in the 12 micrometer region is being made. The resulting five channel instruments are planned for flight on later spacecraft in the series. The APT system will transmit data from any two of the AVHRR channels. The HRPT system will transmit data from all channels. In order to avoid future changes on the spacecraft and in the ground receiving equipment, the TIROS-N HRPT data format is being designed as though the AVHRR were already a five channel instrument. When operating with the four channel instrument, the data from one channel (11 micrometers) will be inserted in the data stream twice so that the basic data format will be the same for both the four- and five-channel versions.

Table 2-7.--AVHRR spectral coverage

<u>Parameter</u>	<u>Ch. 1</u>	<u>Ch. 2</u>	<u>Ch. 3</u>	<u>Ch. 4</u>	<u>Ch. 5*</u>
Spectral range ( $\mu\text{m}$ )	.55-.9	.725-1.0	3.55-3.93	10.5-11.5	11.5-12.5
Detector type	Silicon	Silicon	InSb**	HgCdTe***	HgCdTe***
Resolution (IFOV)	1.3 mr 1.1 km	1.3 mr 1.1 km	1.3 mr 1.1 km	1.3 mr 1.1 km	1.3 mr 1.1 km
Line rate	----- 360 lines per minute -----				

\*Channel 5 will not be included for the first TIROS-N flight, but is included on later TIROS-N/NOAA flights.

\*\*Indium Antimonide

\*\*\*Mercury Cadmium Telluride



The data from the AVHRR will be available from the satellite in four operational modes:

1. Direct readout to ground stations of the Automatic Picture Transmission (APT) class, world-wide, at 4 km resolution, two channels selectable by ground command.
2. Direct readout to ground stations of the High Resolution Picture Transmission class (HRPT) class, world-wide, at 1.1 km resolution, of all spectral channels.
3. Global on-board recording of 4 km resolution data from all spectral channels for commanded readout for processing in the Suitland central facility.
4. On-board recording of data from selected portions of each orbit at 1.1 km resolution for central processing.

### 2.2.3 Data Collection and Platform Location

The TIROS-N satellites will include a new capability for operational polar environmental satellites, a Data Collection and Platform Location System (DCPLS). It will provide for the receipt and storage of data (e.g., temperature, pressure, altitude, etc.) from fixed and moving platforms for later transmission to the central processing facility, and for the location of the moving platforms. The platform location is for the purpose of determining the velocity of the fluid medium in which the platform is immersed (i.e., wind velocity in the case of balloons and ocean current at a depth of the drogue in the case of buoys). The accuracy which will be achieved is a function of the position location accuracy for each fix, the time interval between fixes, the geometry of the satellite and platform paths of flight, and the representativeness/responsiveness of the platform motion. A few of the more interesting DCPLS parameters are tabulated in Table 2-8.

Table 2-8.--DCPLS parameters

<u>System Parameters</u>	<u>Value</u>
Data bit error rate	$2 \times 10^{-5}$
Location accuracy	5-8 km rms
Wind speed accuracy	$\pm 3$ mps
Visibility circle	5° elevation
No. of platforms in circle	200 max.*
Total platforms over globe	2000 max.
<u>Platform Parameters (typical)</u>	
Frequency	401.65 MHz
Emitted power	3 W
Bit rate	400 bps
Message duration	420 ms
Message repetition period	40-80 sec

\*Number of platforms requiring location, velocity determinations, and telemetering four sensor channels, visible in a 5<sup>0</sup> visibility circle. Actual number will depend on mix of platforms.

#### 2.2.4 Space Environment Monitoring

The Space Environment Monitor (SEM) data will also be included in HRPT and beacon transmission. This instrument, consisting of three separate and independent components, is being designed to measure solar proton, alpha particle, and electron flux density, energy spectrum and the total particulate energy disposition at satellite altitude. The three components are:

1. Total Energy Detector (TED).
2. Medium Energy Proton and Electron Detector (MEPED).
3. High Energy Proton and Alpha Detector (HEPAD).

The SEM characteristics are shown in Table 2-9.

Table 2-9.--SEM Instrument Characteristics

<u>Component</u>	<u>Detector</u>	<u>Measurement</u>
TED	Channeltron	0.3 Kev to 20 Kev in 11 bands
MEPED	Solid State	Telescope: Protons 30 Kev to 2500 Kev 5 bands Telescope: Electrons >30 Kev to >300 Kev 3 bands Telescope: ions >6 Mev Omni : Protons >10 Mev, >30 Mev, >60 Mev
HEPAD	Cerenkov Scintillator with photo multiplier	Protons 370 Mev to >850 Mev in 4 bands Alphas >640 Mev and >850 Mev

## 2.3 Orbital Information

The TIROS-N spacecraft will be launched into a near-polar, sun-synchronous orbit at nominal altitudes of 830 and 870 km and will be capable of operating in orbits having a  $0800 \pm 2$  hours local solar time descending node, or a  $1600 \pm 2$  hours ascending node. Elements of the mission orbit are as follows:

- a) Semi-major axis.....7211.54 km
- b) Inclination..... 98.70 degrees
- c) Anomalistic period.....101.58 minutes
- d) Height of perigee..... 833.3 km
- e) Height of apogee..... 833.4 km

## 2.4 Spacecraft Structure and Configuration

The spacecraft configuration will be designed for a two-year life and will be divided into a spacecraft bus subsystem and an instrument subsystem. The spacecraft bus subsystem houses the basic structure/thermal, power, attitude determination and control, and communications and data handling subsystems. The instrument subsystem houses the radiometer, sounder, SEM, DCS, and tape recorder subsystems.

The structure uses, as a baseline, a Block 5D (Air Force funded satellite) integrated structure modified as required for the NOAA mission. An integrated Block 5D structure consists of a solar array, an injection motor structure, and an equipment support module and instrument mounting platform. The total estimated weight at launch of TIROS-N including the injection motor and payload is 3100 pounds.

The spacecraft thermal control is designed for all sun angles between  $0^{\circ}\text{C}$  to  $68^{\circ}\text{C}$ , internal maximum and minimum power dissipation, and for end-of-mission life conditions. Active and passive thermal control similar to that used on Block 5D should confine the temperature of the spacecraft internal equipment to a range of  $5^{\circ}\text{C}$  to  $25^{\circ}\text{C}$  and the instruments to a range of  $10^{\circ}\text{C}$  to  $30^{\circ}\text{C}$ .

A drawing of the TIROS-N spacecraft is shown in Figure 2-1.

## 2.5 Spacecraft Electronic Systems

The TIROS-N spacecraft uses a variety of telecommunications links for receiving and transmitting sensor data, for transmitting spacecraft house-keeping and status data, and for receiving commands from selected ground stations. A three-axis attitude control system permits control of the spacecraft attitude. Electrical power is generated by an independently driven solar array, with storage provided by batteries for eclipse periods,

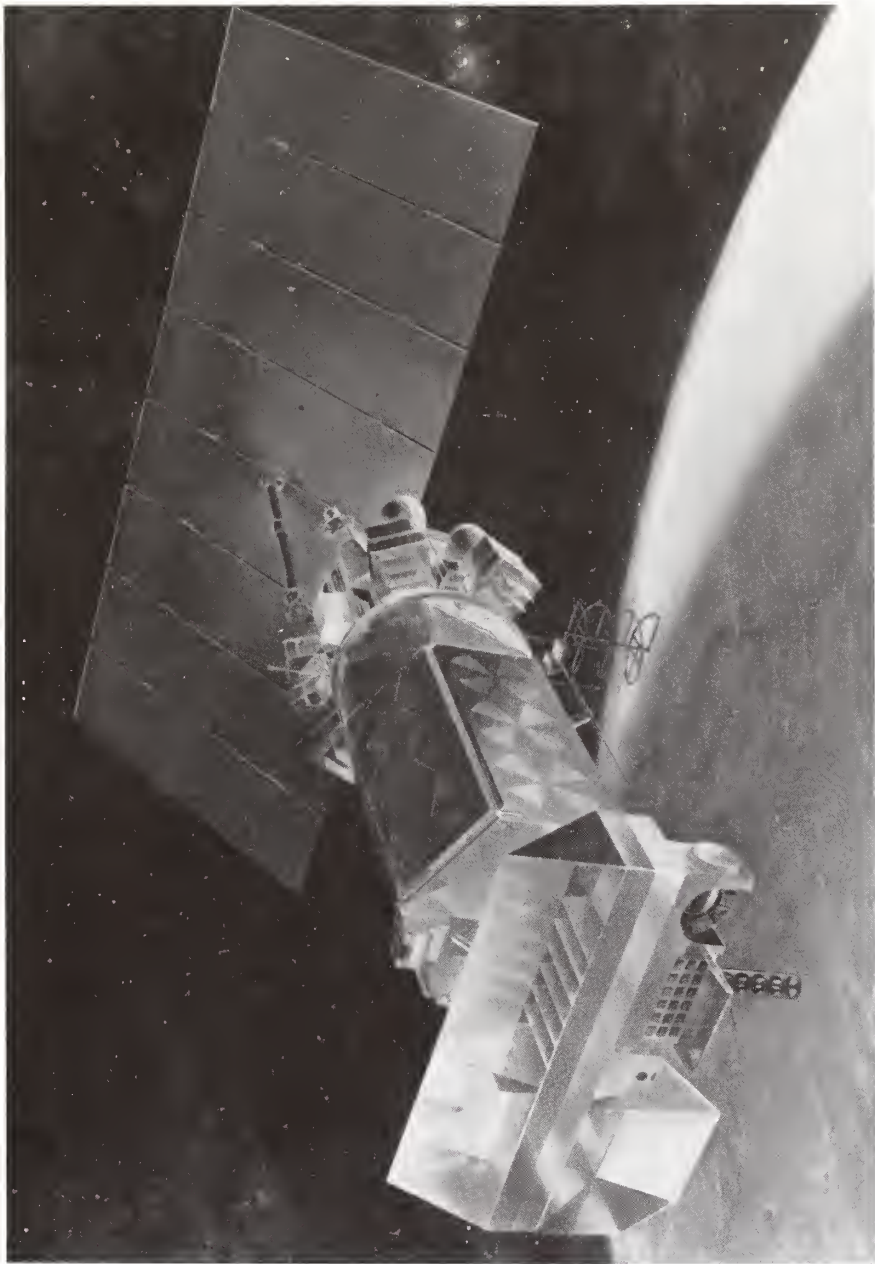


Figure 2-1.--TIROS-N spacecraft

peak loads, and launch. A simplified block diagram of the spacecraft electronic systems is presented in Figure 2-2.

### 2.5.1 Power Subsystem

The power subsystem provides +28 vdc regulated power and +10 v and +5 vdc power for control signal interfacing. The power subsystem is a direct energy transfer type and will provide 430 watts average power at end of life. Two 30 ampere-hour batteries are supplied.

### 2.5.2 Attitude Determination and Control Subsystem (ADACS)

The ADACS to be used consists of a primary attitude determination subsystem, a sun sensor unit, an earth sensor assembly, reaction wheels, and torque coils. During normal operation, the ADACS will stabilize the spacecraft with the yaw axis aligned with the local geodetic vertical and the roll axis aligned with the orbit plane.

### 2.5.3 Telecommunications System

The telecommunications system consists of a very high frequency (VHF), ultra high frequency (UHF), and S-band links for the transmission and reception of data. In general, the spacecraft is capable of downlink transmissions of TIP, HRPT, APT, Global Area, Limited Area, and dump TIP data. The specific links used depend on the particular interfacing ground station as well as the phase of the mission. Commanding may be accomplished from either of the two NOAA/NESS Command and Data Acquisition (CDA) Stations. The DCS uplink signals are limited by the distribution of the remote DCP's.

The downlinks and uplinks of this system are as follows:

- a) Downlinks -- The spacecraft downlinks are on two VHF and three S-band frequencies.
  - 1) One VHF downlink will normally contain real-time TIP 8.32 kbps split phase PCM data. The data phase modulates the carrier. Two carrier frequencies (136.77 MHz and 137.77 MHz) are available on each spacecraft. Only one frequency can be transmitting at a time. The selection of frequency is determined by ground command.



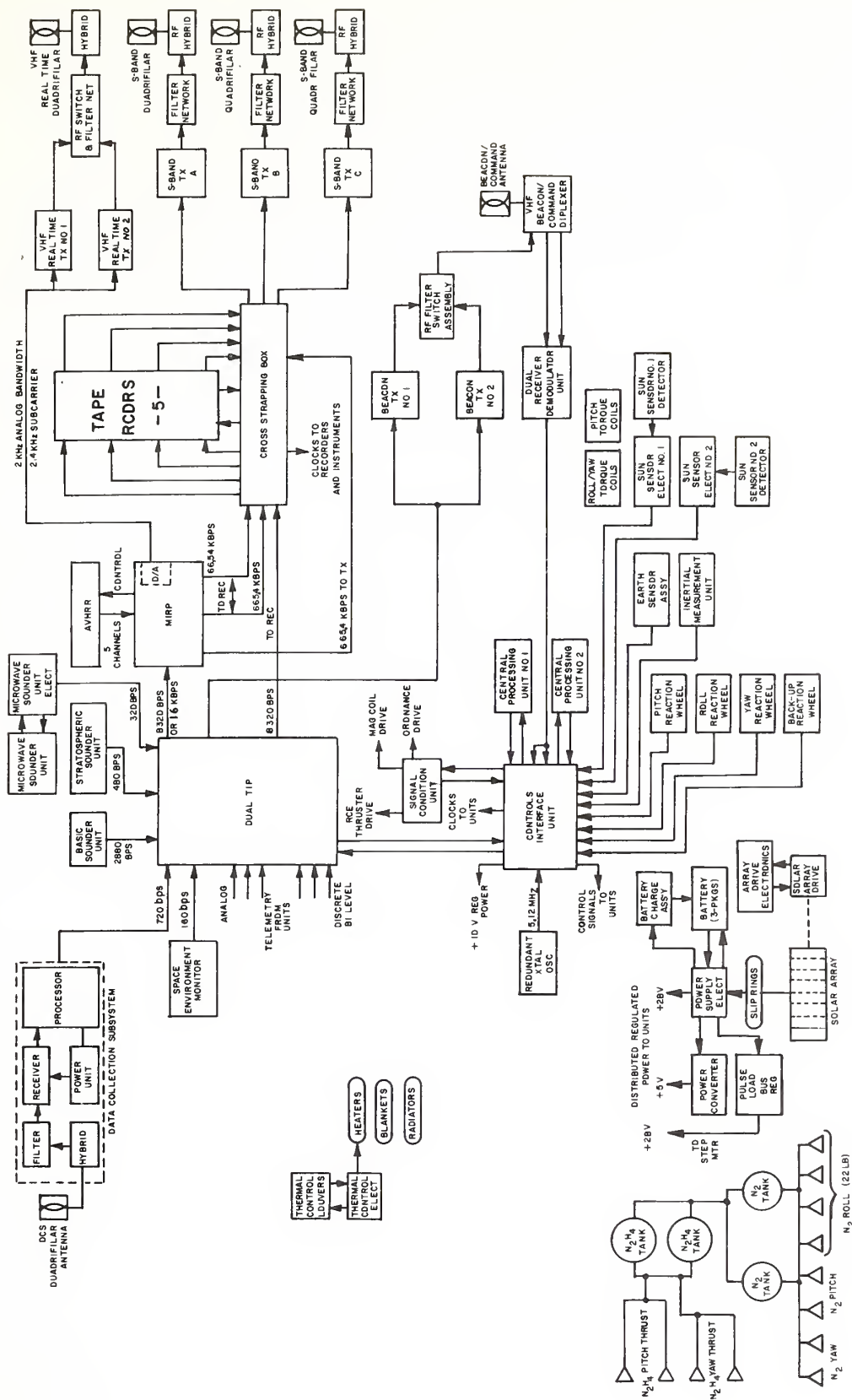


Figure 2-2.--TIROS-N electronic systems (orbit mode)

- 2) The second VHF downlink will normally contain analog APT data. The APT data amplitude modulates a 2.4 kHz subcarrier which, in turn, frequency modulates the carrier. Two frequencies (137.5 and 137.62 MHz) are available on each spacecraft. Only one frequency can be utilized at any one time. The frequency selection is determined via ground command.
  - 3) The three S-band downlinks provide for four data transmissions: HRPT, Global Area, Limited Area, and Stored TIP. The three transmitters operate at different frequencies (1698.0, 1702.5, and 1707.0 MHz) within a 15 MHz band centered at 1702.5 MHz with PSK modulation. Each transmitter is coupled to one of three S-band quadrifilar antennas. The center frequency transmitter is left-hand circularly polarized while the other two are right-hand circularly polarized. One right-hand circularly polarized link is used continuously to support the HRPT link unless failures occur.
- b) Uplinks -- The uplinks capable of being received by the spacecraft are VHF command and UHF DCS data.
- 1) The UHF uplink is used to receive data from the data collection platform (DCP) system. This uplink is demodulated, processed, and the data presented to the TIP for downlinking to the ground station and for recording on the spacecraft recorders. The UHF uplink frequency is 401.65 MHz.
  - 2) The VHF command uplink can only be generated by the assigned NESS ground stations. The VHF uplink frequency is 148.56 MHz and contains the 1000 bps FSK command information.

A simplified telecommunications system is presented in Figure 2-3.

#### 2.5.3.1 TIROS Information Processor (TIP)

The TIP formats data signals and status telemetry into one 8320 bps signal and distributes it where required. Inputs to the TIP include: the TOVS data, the SEM data, the received data collection data, housekeeping telemetry, and on-board computer data. These data are time division multiplexed into a format determined by a stored program within the TIP.

The TIP can operate in each of three modes: mission mode, boost mode, and dwell mode. In the mission mode (orbital data and on-board computer data), data from the low rate instruments, housekeeping telemetry, and computer data is formatted into a 32-second major frame consisting of 320 minor frames. Each frame is 0.1 second in duration and consists of 104-8-bit words. The boost mode format provides selected bi-level and analog telemetry, computer data, and digitized telemetry from three vibration sensors. The boost mode data rate is 16 kbps and is used only for the launch phase. In the dwell mode, a wideband sampling technique allows for sampling a particular analog telemetry point by preempting every data word



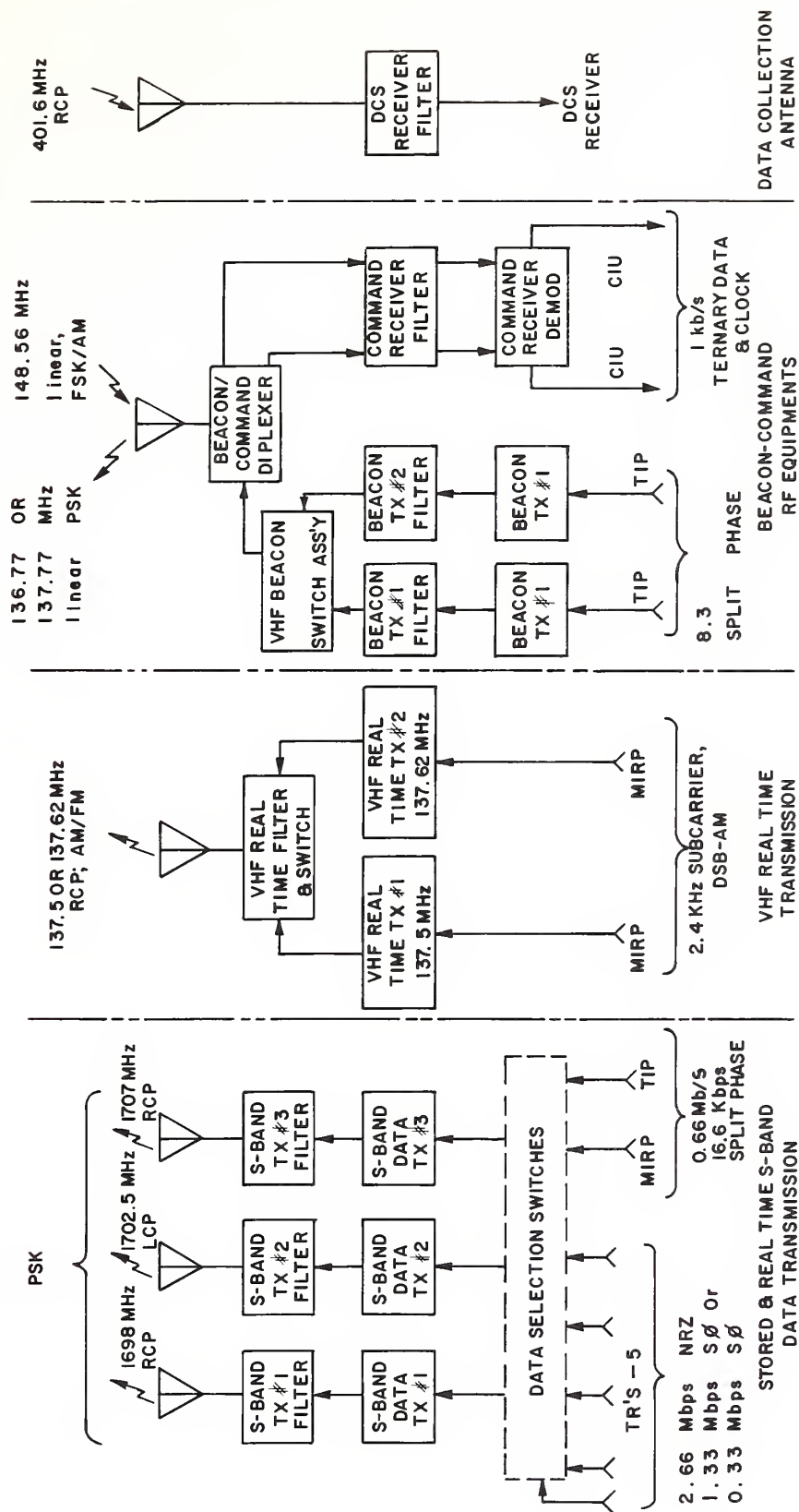


Figure 2-3.--Simplified telecommunication system

in the format (except sync, command verification, spacecraft address, and frame status). This mode can be used to monitor critical operations or as a troubleshooting tool.

The TIP output data stream is directed to: the VHF link for continuous real-time transmission, the digital recorders during multiple missed orbits for later playback, and the MIRP for multiplexing with the AVHRR data (HRPT, etc.).

#### 2.5.3.2 Manipulated Information Rate Processor (MIRP)

The function of the MIRP is to buffer, process, and format digital data from the four or five AVHRR channels and TIP into the required output formats. The MIRP processes the AVHRR words to produce 10,240 words of earth data per scan. The scan rate is six lines per second and each word has ten bits. The unit configuration, processing algorithms, and output data rates are consistent with a five-channel AVHRR. When operating a four-channel AVHRR, one of the four channels will be repeated to maintain these rates. The MIRP contains large multiaccess buffer stores to: 1) permit a continuous output of earth scan data during the time the AVHRR is viewing space, and 2) process the earth scan data into the desired digital signals. The MIRP output formats are:

- a) High resolution video data (665.4 kbps) sent to the S-band transmitters for real-time transmission (HRPT),
- b) Limited high resolution data (665.4 kbps) sent to the recorders for storage and later playback (LAC),
- c) Low resolution global stored data (66.54 kbps) sent to the recorders for storage and later playback (GAC), and
- d) Medium resolution video data (APT analog on 2.4 kHz subcarrier) sent to VHF transmitter for real-time transmission.

#### 2.5.3.3 Digital Data Recorders

Five digital data recorders comprise the TIROS-N recording system and utilize one-mil thick,  $\frac{1}{4}$ -inch wide tape. Each digital data recorder contains two tape transports and one electronics package. Only one tape transport per recorder can be operated at a time. The high resolution video data and the global stored data, which were recorded at 665.4 kbps and 66.54 kbps, respectively, are reproduced as 1.33 Mbps split phase or 2.66 Mbps NRZ data and sent to the S-band transmitters. The TIP, which was recorded as 8320 bps, is reproduced as 332.7 kbps split phase data and sent to the S-band transmitters. When more than one recorder is played back, they are accomplished in parallel. However, the maximum number which can be transmitted at one time is three if the HRPT is deleted.

#### 2.5.3.4 VHF Data Downlinks

The real-time TIP and APT data are simultaneously transmitted by both VHF downlinks. The VHF downlink characteristics are as follows:

- 1) Frequency
  - a) TIP: 136.77, 137.77 MHz
  - b) APT: 137.5, 137.62 MHz
- 2) Frequency stability  $\pm 2 \times 10^{-5}$
- 3) Transmitter power
  - a) TIP: 1.0 watt
  - b) APT: 5.5 watts, beginning of life  
5.0 watts, end of life
- 4) Antenna gain, TIP
  - a) on axis, nadir +5.8 dBi
  - b) 5 degree elevation -6.0 dBi
  - c) Gain over 90% of sphere -14.0 dBi
- 5) Antenna gain, APT: see Figure 2-4
- 6) Polarization
  - a) TIP: linear
  - b) APT: right circular
- 7) Antenna type
  - a) TIP: dipole
  - b) APT: quadrifilar helix
- 8) Total antenna-transmitter loss
  - a) TIP: 3.5 dB
  - b) APT: 2.1 dB
- 9) Modulation
  - a) TIP: PCM/PSK
  - b) APT: Analog/FM

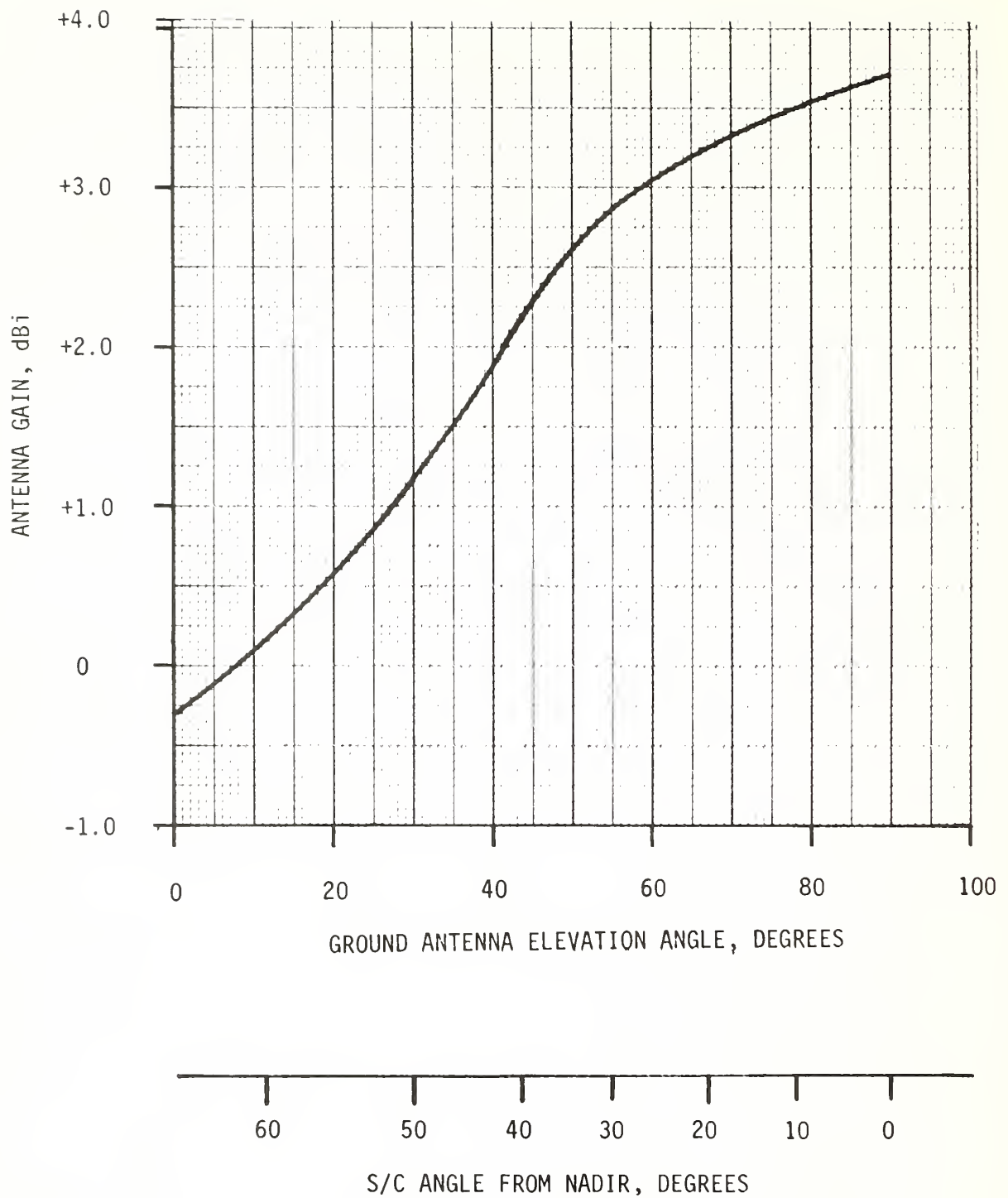


Figure 2-4.--APT antenna gain

- 10) Modulation index
  - a) TIP:  $67 \pm 7.5$  degrees, peak
  - b) APT:  $17 \pm 0.85$  kHz, peak
- 11) Modulation rate on carrier
  - a) TIP: 8.32 kbps
  - b) APT: 2.4 kHz subcarrier
- 12) APT subcarrier modulation index:  $\leq 92\%$  AM
- 13) APT analog baseband: 1.6 kHz
- 14) TIP data code: split phase
- 15) Formats
  - a) TIP: see Figure 2-5
  - b) APT: see Figure 2-6 and 2-7
- 16) Transmitter operation: continuous

#### 2.5.3.5 S-Band Data Downlinks

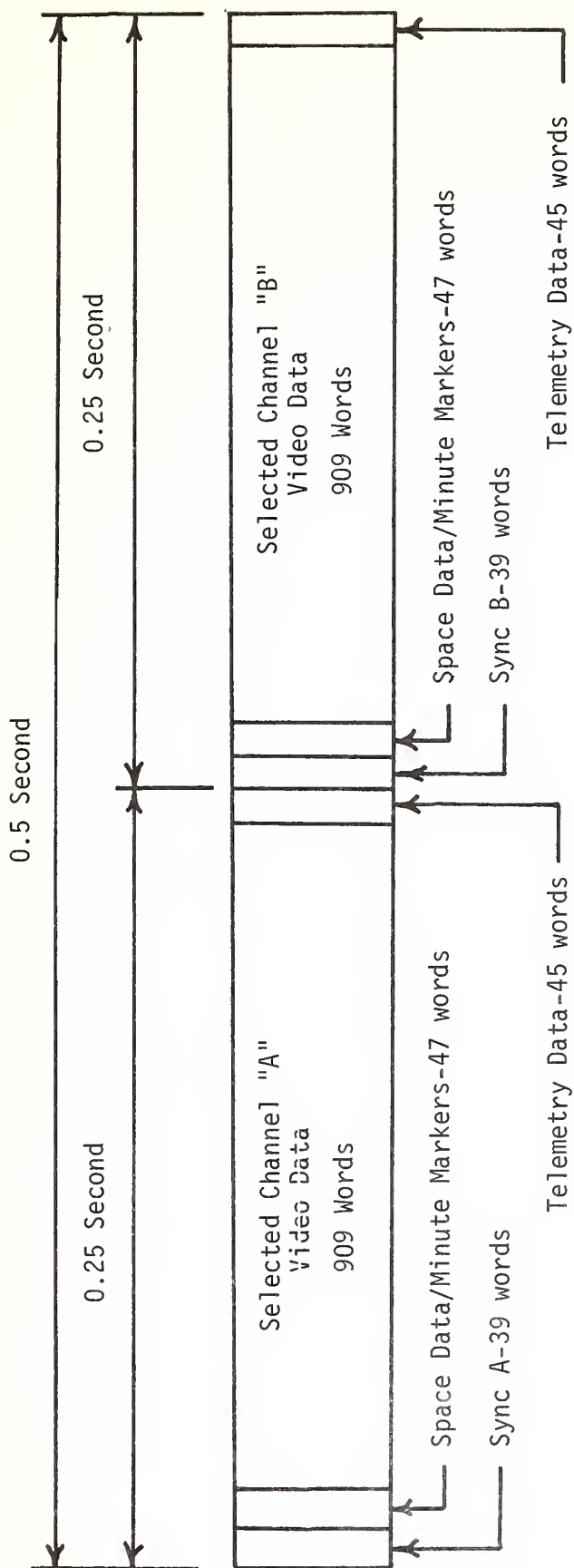
The S-band system provides three transmitters and antennas (all three alike) to transmit HRPT, LAC, GAC and Stored TIP data for the orbital phase. Characteristics of the S-band links are as follows:

- 1) Frequencies: 1698.0, 1702.5, 1707.0 MHz
- 2) Frequency stability:  $\pm 2 \times 10^{-5}$
- 3) Transmitter power: 6.35 watts
- 4) Antenna gain: see Figure 2-8
- 5) Polarization
  - a) 1702.5 MHz left-hand circular
  - b) 1698, 1707 MHz right-hand circular
- 6) Antenna type: quadrifilar helix
- 7) Total transmitter-antenna loss: 2.8 dB
- 8) Modulation: PCM/PSK
- 9) Modulation index:  $67 \pm 7.5$  degrees, peak



2-18





- Notes:
1. Equivalent Output Digital Data Rate is 4160 Words/Second.
  2. Video Line Rate - 2 Lines/Second.
  3. APT Frame Size - 128 Lines.
  4. Any two of the five AVHRR channels may be selected for use.
  5. Sync A is a 1040 Hz square wave - 7 cycles.
  6. Sync B is a 832 pps pulse train - 7 pulses.
  7. Each of 16 telemetry points are repeated on 8 successive lines.
  8. Minute markers are repeated on 4 successive lines, with 2 lines black and 2 lines white.

Figure 2-6.--APT video line format (prior to D/A converter)



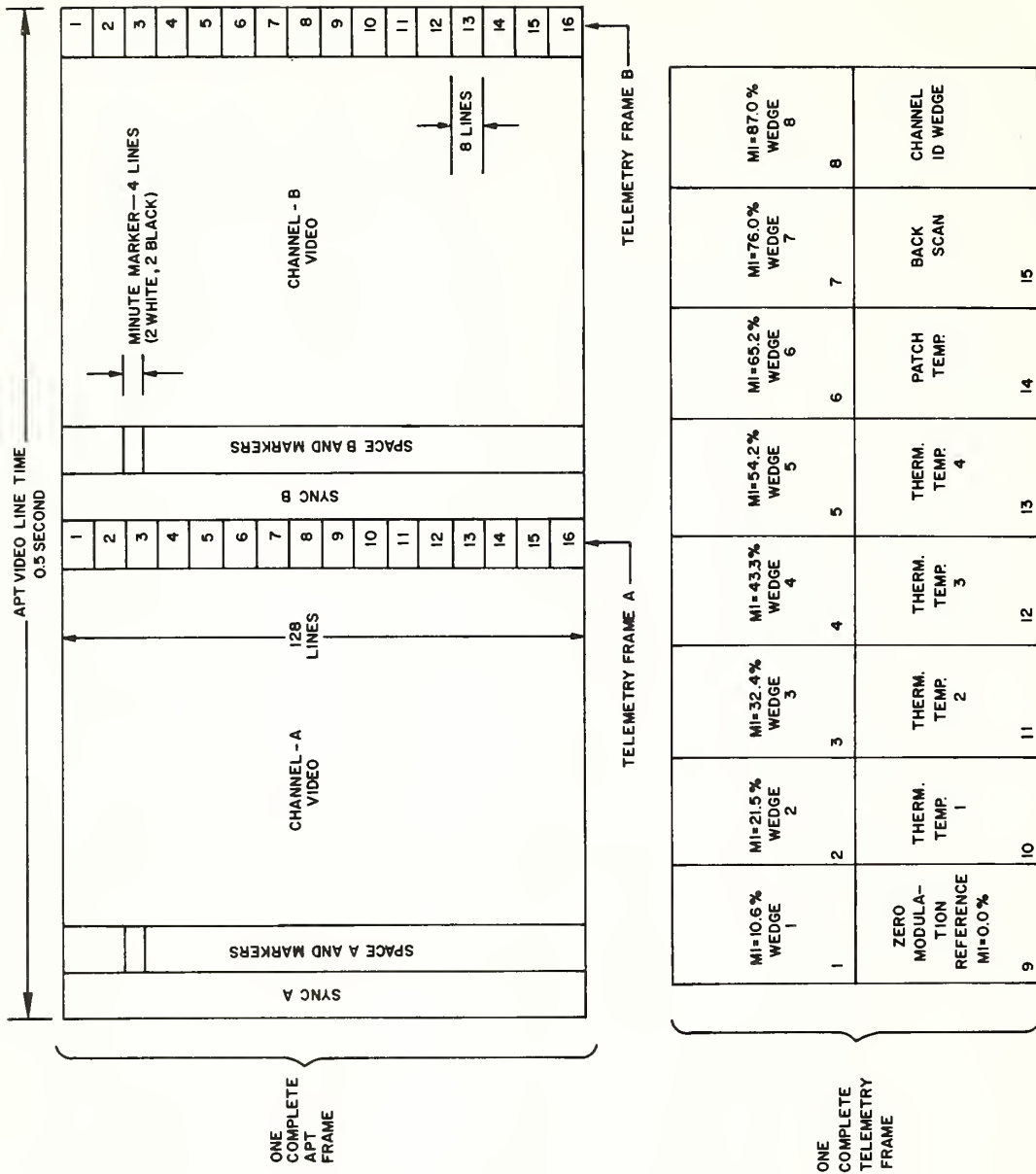


Figure 2-7.-- APT frame format

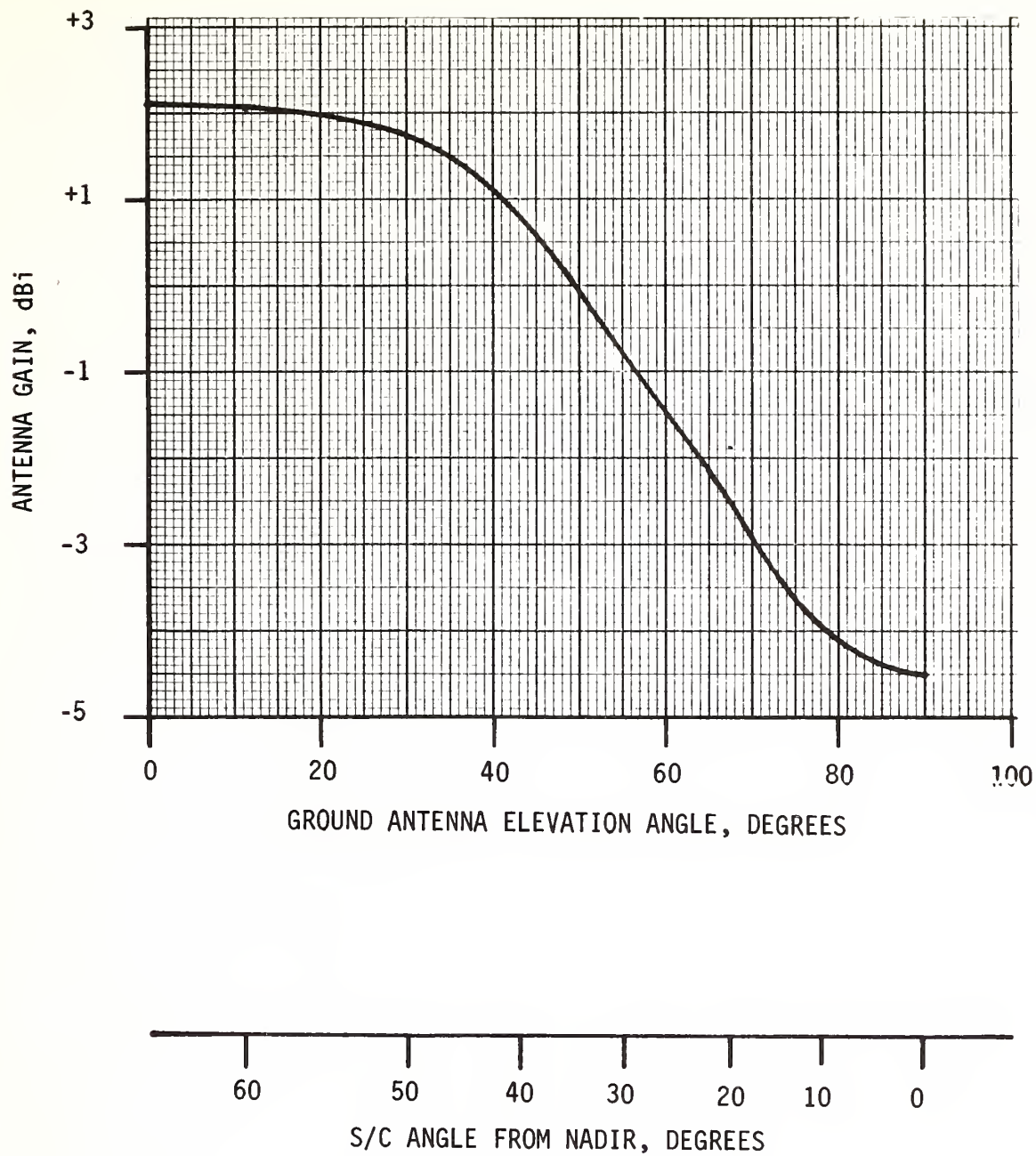


Figure 2-8.--S-band antenna gain.

#### 10) Modulation rates

- a) Stored TIP: 0.3327 Mbps
- b) HRPT : 0.6654 Mbps
- c) LAC : 1.3308/2.6616 Mbps
- d) GAC : 1.3308/2.6616 Mbps

Note: For the remainder of this document the modulation rates are truncated to 0.33, 0.66, 1.33, and 2.66 Mbps.

#### 11) Modulation code

- a) Stored TIP: split phase
- b) HRPT : split phase
- c) LAC
  - 1) 1.33 Mbps: split phase
  - 2) 2.66 Mbps: NRZ
- d) GAC
  - 1) 1.33 Mbps: split phase
  - 2) 2.66 Mbps: NRZ

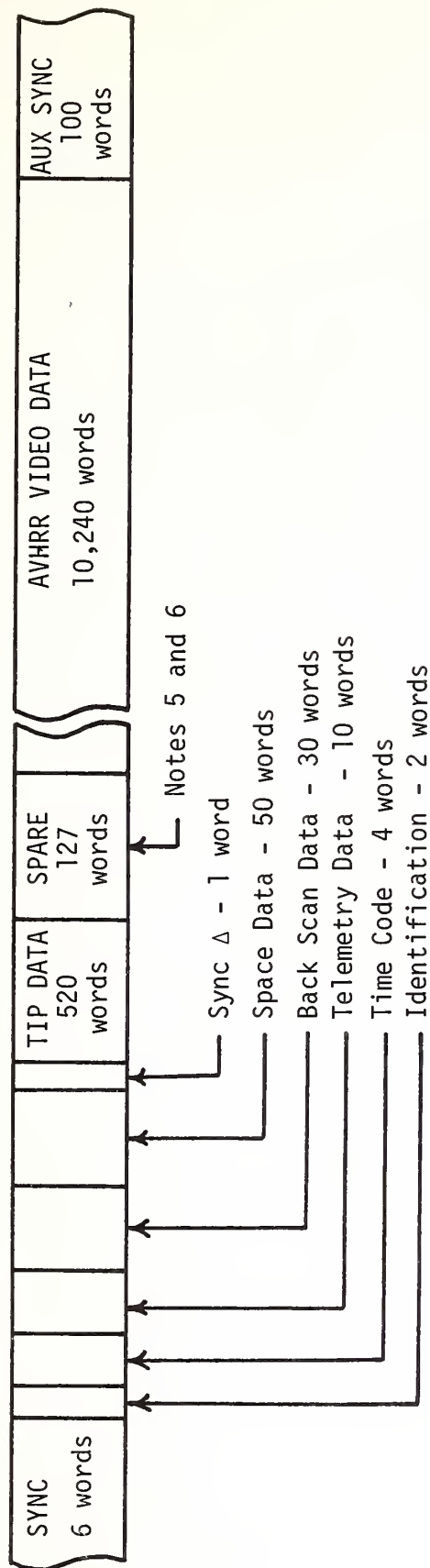
#### 12) Formats

- a) Stored TIP: TIP recorded on recorder and played back in reverse (see Figure 2-5)
- b) HRPT/LAC : See Figure 2-9
- c) GAC : See Figure 2-10

#### 2.5.3.6 UHF Uplink

The UHF uplink provides for the receipt of the data collection platforms. Characteristics of the UHF are as follows:

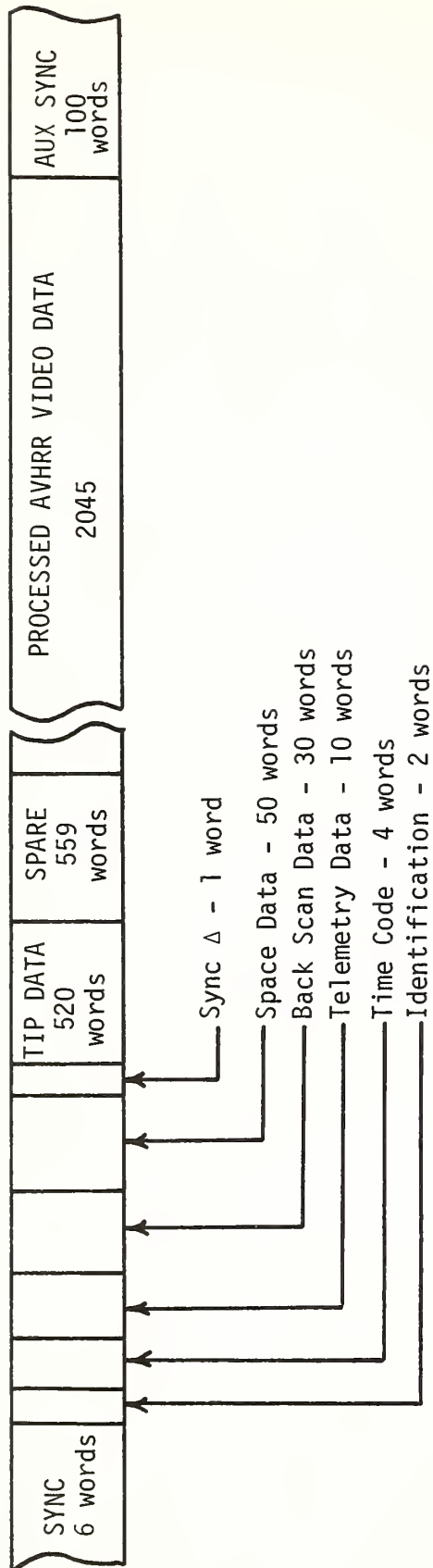
- 1) Frequency : 401.65 MHz
- 2) Antenna type : Quadrifilar helix
- 3) Antenna gain, on axis : not specified
- 4) Antenna gain, 5 degree elevation : -4.6 dBi
- 5) Antenna polarization : right-hand circular
- 6) Loss : 1.6 dB



Notes:

- 1) Minor Frame Length - 11,090 words
- 2) Three minor frames per major frame
- 3) Minor Frame Rate - 6 frames/second HRPT
- 4) Word Length - 10 bits/word
- 5) HRPT Output - All spares are 10th degree P-N code (bar)  
LAC Output - All spares are zero.
- 6) Spare words used for instrument growth
- 7) LAC data is randomized between syncs by a 10th degree P/N code. LAC data is sent in reverse order to the ground.

Figure 2-9.--TIROS-N HRPT/LAC frame format



- Notes:
- 1) Frame Length - 3327 words
  - 2) Word Length - 10 bits
  - 3) Data is randomized between syncs by a 10th degree P-N code. Data is sent in reverse order to the ground.
  - 4) Spare words are zero prior to randomization.

Figure 2-10.--GAC frame format

### 2.5.3.7 VHF Command Uplink

The VHF command uplink provides for the receipt of command data. Characteristics are as follows:

- 1) Frequency : 148.56 MHz
- 2) Frequency stability :  $\pm 2$  kHz
- 3) Minimum received EIRP for  
BER =  $10^{-6}$  : -87.0 dBm
- 4) Polarization : linear
- 5) Modulation
  - a) carrier : AM
  - b) S/C data : 1000 bps ternary FSK
  - c) clock : AM on subcarrier
- 6) Modulation index
  - a) carrier : 85 %
  - b) clock : 50 %
- 7) IF bandwidth 3 dB :  $\geq 42$  kHz
- 8) Clock
  - a) Rate : 1000 Hz, sinewave
  - b) Bandwidth : 60 Hz
- 9) Mark frequency : 8 kHz
- 10) Space frequency : 12 kHz
- 11) Idle frequency : 10 kHz
- 12) Antenna characteristics
  - a) on axis, nadir : +3.7 dBi
  - b) 5 degree elevation : -14 dBi
  - c) gain over 90 % of  
sphere : -18 dBi

Note: Antenna characteristics based on a right-hand circularly polarized uplink.





## SECTION 3 - S-BAND/VHF THRESHOLDING PARAMETERS

### 3.1 Introduction

The following paragraphs discuss and define the critical parameters required to define the RF front-end subsystem prior to the receiver/de-modulator. These parameters control the dynamic range of received signal levels and the threshold sensitivity of the receiving system. Each parameter will be discussed for the links that it applies to.

While reading the following paragraphs, it should become obvious that many solutions will exist that satisfy TIROS-N. It is the intention of this document to only present the information required to develop the many solutions. The ground system designer is expected to be able to do compromising and trading-off among the solutions in order to achieve the most optimized system for his use. A further note is required: The following paragraphs discuss what is required for each link separately. For example, noise temperatures and gains will be shown for the 0.66 Mbps link. Prior to designing, the user must decide how many RF links are to be supported. For the S-band, the user must also decide the highest bit rate he will receive. As a rule, satisfying the highest bit rate to be supported will enhance the ability to receive the lower rates. For example, if the high rate is designed for a 3 dB margin then the lower rates will be better than the 3 dB margin in the amount of the ratio of the high rate to the lower rate ( $10 \log \text{High Rate/Low rate}$ ). For the VHF, the user must decide if only one link (PCM/TIP or APT) is to be supported or if both links are to be supported. If only one link is to be utilized, then the procedure is straight forward. However, if both links are considered then the designer should calculate both links thoroughly remembering which items are common. For example, the preamp bandwidth must be wide enough for both links and the antenna gain/noise temperature applies to both links simultaneously. As a general rule, if common elements are used for both links, then the PCM/TIP link is the critical link for the gain/temperature calculation and the APT link is the critical link for the overall gain calculation. If common elements are not used to support both links, then each link should be calculated separately. In summary, for the VHF or S-band links utilizing common elements, choosing the respective critical links to design from will result in meeting the minimum safety margin for the one link while the other link will have quite a lot more margin. The designer must also remember that the VHF and/or the S-band system must pass all respective RF links. Thus, the preamps/paramps, etc. bandwidths must pass all links and that the system gains will apply to each link. More will be said on this subject in the appropriate paragraphs. Section 5, Examples, also will show how to properly design for multiple links.

### 3.2 Polarization

Before commencing the gain/noise temperature/dynamic range discussion, a few words on antenna polarization is required. The adequacy of a radio frequency link is influenced by two major factors. First, the RF wave must contain adequate power at the receiving antenna location and second, polarization mismatch between the incoming wave and the receiving antenna must be small enough so that the loss from cross polarization is tolerable. It is obvious that both criteria must be satisfied. The act of propagating adequate power to a receiving point does not necessarily ensure adequate reception of that power. A mismatch between the polarization of the incoming electromagnetic wave and that of the receiving antenna may be such that relatively little or no energy can be extracted from the wave. Polarization is a term used to describe the behavior of the electrical vector in a fixed plane normal to the direction of propagation as an electromagnetic wave moves through a medium. Linear and circular polarizations are limiting conditions of the more general elliptical polarization. However, since circular and linear polarization are most commonly used, they are considered here.

For this document, the polarization defined for the transmitting antenna is the polarization of the electromagnetic wave actually propagated. The receive antenna polarization is defined as the polarization sense which the antenna fully responds to the propagated wave. Thus, if the source sends RHC then the receive antenna must also be RHC to not be cross polarized. Average losses due to cross-polarization are assumed to be those given in the following table:

<u>Transmit Antenna</u>	<u>Receive Antenna</u>	<u>Polarization Loss</u>
LHC	LHC	0 dB
RHC	RHC	0 dB
LHC	RHC	} 15 dB average, VHF
RHC	LHC	
		} 20 dB average, S-band
Linear	Linear	} 0 dB, linears aligned 3 dB, average 15 dB, worst case
Circular	Linear	3 dB
Linear	Circular	3 dB

The above table applies to a ground receiving system which employs only a single channel receiver, i.e., only one polarization and one receiver. However, if polarization diversity techniques are used (i.e., two received polarizations with optimal combining), then the ground system is designed to receive two orthogonal polarizations resulting in minimal power loss (on the order of 0.5 dB). If both polarization channels contain equal signal, then an improvement of up to 3 dB could exist. However, typical ground receiving systems do not utilize the polarization diversity

techniques because of the cost and complexity required.

For TIROS-N the following polarizations are used:

<u>Frequency, MHz</u>	<u>Polarization</u>
136.77, 137.77	Linear
137.5, 137.62	RHC
1698, 1707	RHC
1702.5	LHC

If unmatched antennas are used, then the above cross polarization losses should be applied to the results contained in this section. The method on how to accomplish this is shown in the appropriate paragraphs.

### 3.3 Receive Antenna Gain and Total System Noise Temperature

In any receiving system, a specification normally exists which defines the ability of the system to correctly receive data in the presence of noise. This ability is usually defined as the sensitivity of the system and is characterized by stating the lowest possible received signal level the system will use without exceeding a known error rate, distortion, etc. This sensitivity specification is also called the threshold of the system. For space applications and the TIROS-N RF system, two factors used to describe the system threshold are the receive antenna gain and the total system noise temperature. Prior to defining the two factors, two considerations must be decided. The first consideration concerns the margin of safety above the threshold that the user desires to achieve. The second consideration is based on the fact that the received signal, hence the dB's above threshold, will vary as the distance changes between the spacecraft and the ground user. Thus, before designing the receive antenna gain and total system noise temperature, the user must decide upon the minimum receive antenna elevation angle and the minimum safety margin above threshold at the minimum antenna elevation angle to be used.

#### 3.3.1 Results

The two factors, antenna gain and noise temperature, can be combined into a single parameter known as G/T where G is the receive antenna gain and T is the total system noise temperature. The G/T has the units of dB and is found by the following:

$$G/T = \text{antenna gain in dB} - \text{noise temperature in dB.}$$

The G/T versus antenna elevation and safety margin is calculated in Appendix A, and the results are plotted in the following figures:

<u>Figure</u>	<u>Data Link</u>
3-1	VHF PCM/TIP
3-2	VHF APT, IF BW = 50 kHz
3-3	S-band, bit rate = 0.66 Mbps

Prior to using the figures, the designer must decide upon the minimum antenna elevation and minimum safety margin he wishes to support. For the VHF, if both PCM/TIP and APT are to be supported, then he should use the PCM/TIP G/T for both links since it normally thresholds first. For the S-band, the figure for the bit rate of 0.66 Mbps must be used and a correction factor must be applied if the desired maximum bit rate is different from 0.66 Mbps. The correction factor is described in paragraph 3.3.2. An interesting observation is noted for the S-band G/T's. As shown, the G/T decreases to an angle of about 40 degrees and then increases again until the 90 degree angle. This is caused mainly by the spacecraft antenna gain profile. However, since only one G/T can be used to design the system, a further condition is required for the S-band. As shown, the G/T values are the same at 90 degrees as the 20 degree elevation. Thus, if the minimum antenna elevation angle to be supported is higher than 20 degrees, the 20 degree value should be used. In this way, the total pass can be supported without loss of data. Using the required G/T from the figures, the designer can now optimize his gain versus temperature for his particular use using the above equation.

### 3.3.2 Corrections to Results

After determining the G/T from the figures, the designer should now decide if a correction factor should be applied. The corrected G/T is as follows:

$$CG/T = G/T + C$$

where: CG/T = corrected G/T  
 G/T = G/T from the figures  
 C = correction factor

For the VHF PCM/TIP, the correction factor is

$$C = CP$$

where: CP = Cross polarization loss discussed under paragraph 3.2.

For the VHF APT, the correction factor is

$$C = CP + 10 \log \left( \frac{BW}{50 \text{ kHz}} \right)$$



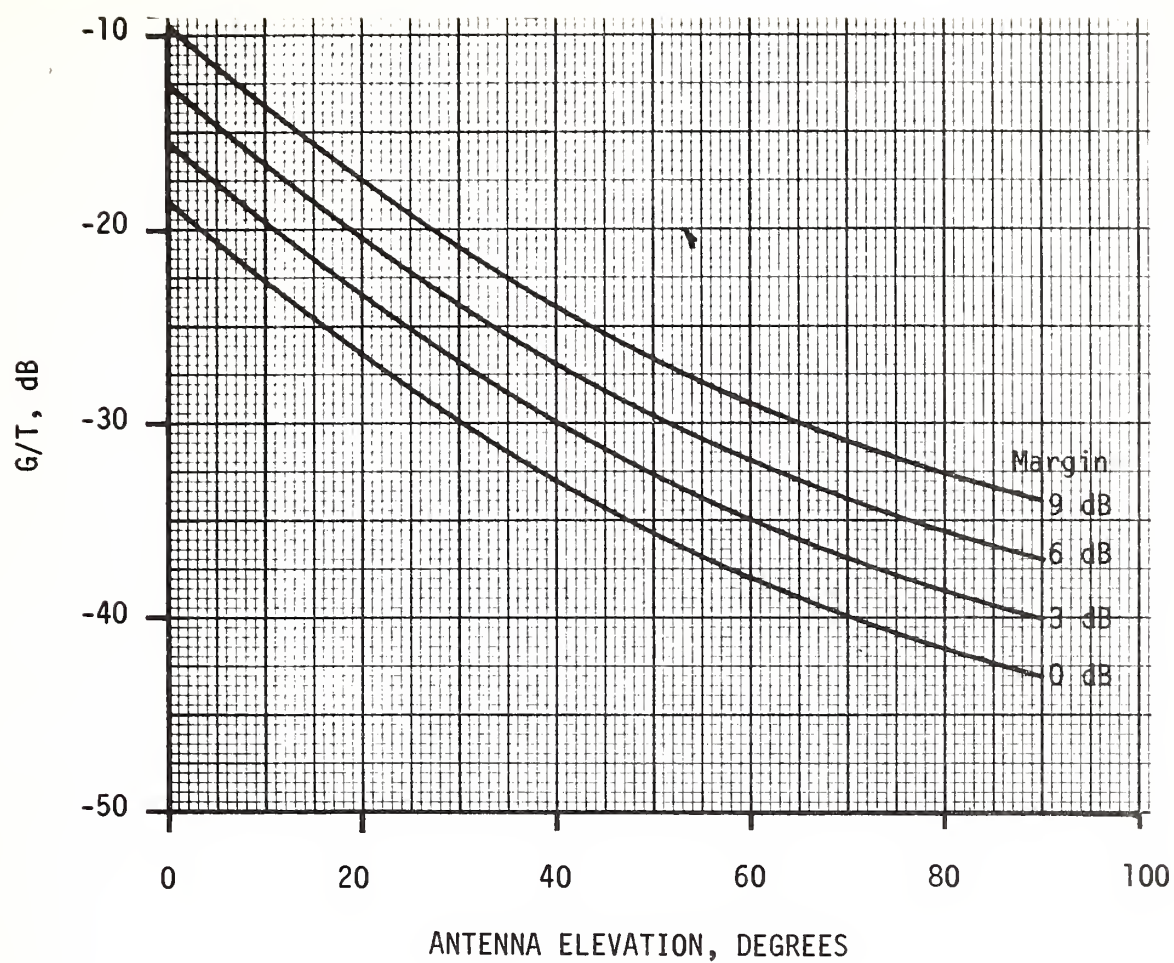


Figure 3-1.--VHF PCM/TIP G/T

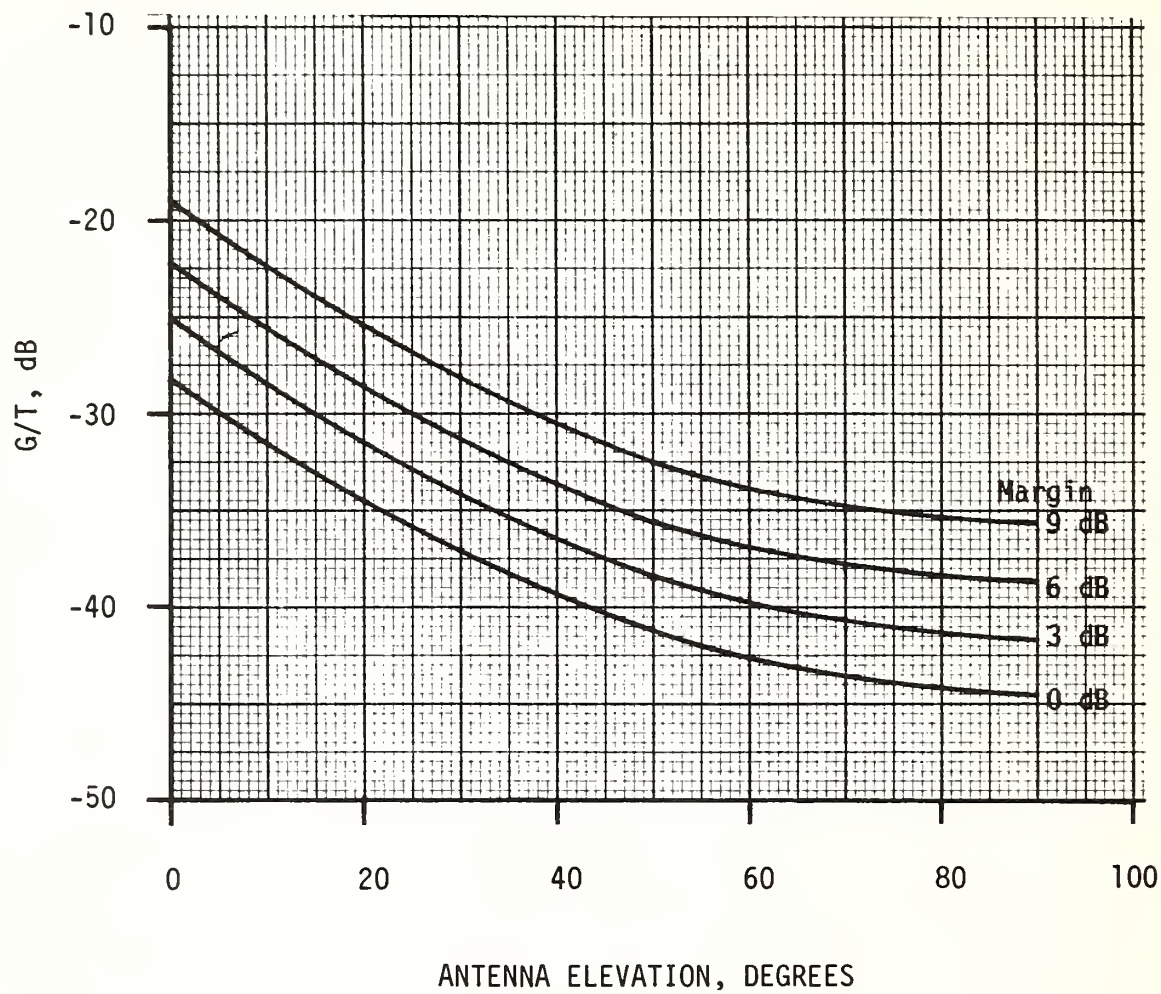


Figure 3-2.--VHF APT G/T  
IF BW = 50 kHz



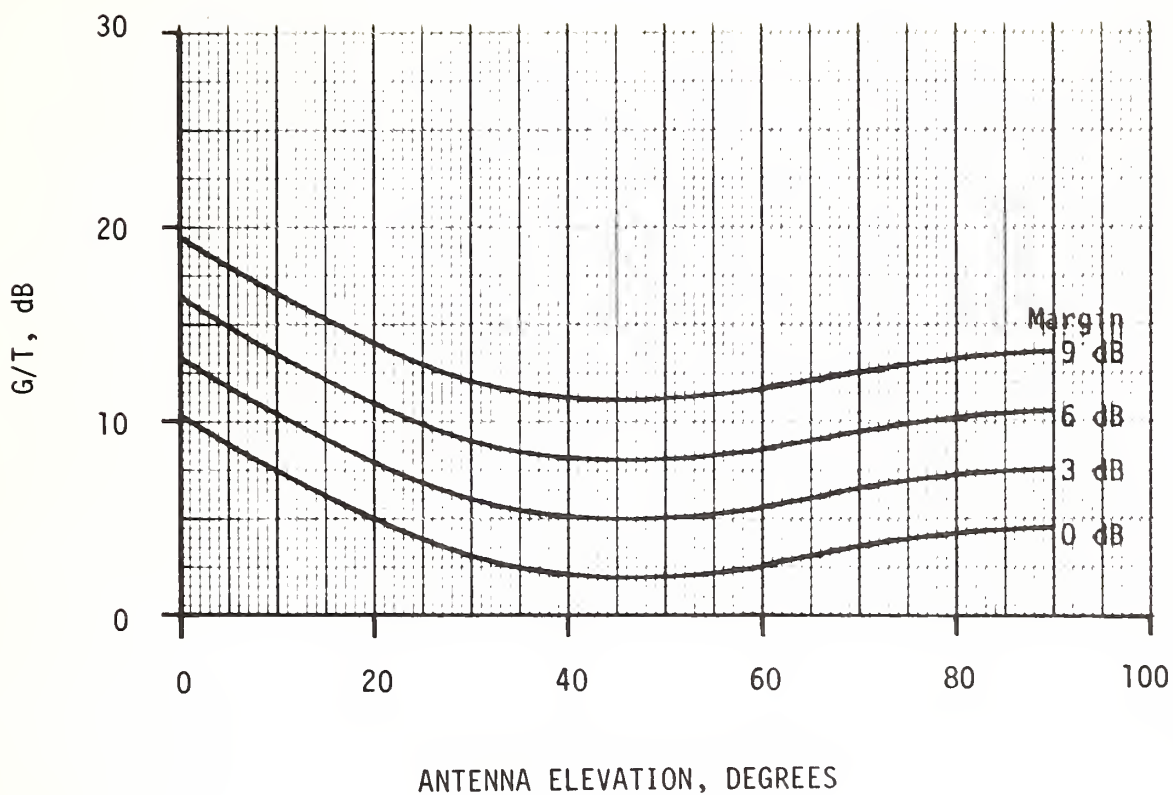


Figure 3-3.--S-band G/T  
bit rate = 0.66 Mbps

where: CP = Cross polarization loss discussed under paragraph 3.2.  
BW = RCVR IF

Note: The designer is cautioned against using a receiver IF bandwidth of less than 50 kHz since lower bandwidths would seriously degrade the signal.

For the S-band, the correction factor is

$$C = CP - CI + 10 \log \left( \frac{\text{Bit Rate}}{0.66 \text{ Mbps}} \right)$$

where: CP = Cross polarization loss discussed under paragraph 3.2.

CI = Correction to the adjacent channel interference shown in Table A-6, Appendix A. A value of -3.8 dB was used assuming that all S-band links are transmitting at the same time. If only one link is modulated and transmitted the value should be 0 dB in the table. To apply the correction here, a value of +3.8 should be used for CI if only one link is operating while a CI of 0 should be used if more than one link is radiating.

Bit Rate = The highest bit rate the user desires to support.

### 3.3.3 Example

Two examples will clarify how to determine the G/T.

#### EXAMPLE 1

For Example 1, both APT and PCM links are to be supported at a minimum elevation angle of 15 degrees with a safety margin of 6 dB. A 100 kHz IF receiver will be used for the APT. A RHC antenna having a 25 dB gain is also used for both links.

From Figure 3-1, we find a G/T of -18.5 will satisfy the PCM link. Figure 3-2 shows a G/T of -27 for the APT. We now determine the correction factors to be applied.

For PCM,  $C = CP$   
 $CP = 3 \text{ dB}$ , since we have a linear to circular match.

Thus  $C = 3$  and the PCM G/T = -15.5 dB

For APT,  $C = CP + 10 \log \left( \frac{BW}{50 \text{ kHz}} \right)$   
 $CP = 0 \text{ dB}$ , since we have a RHC to RHC match.

$$\begin{aligned} BW &= 100 \text{ kHz} \\ C &= 0 + 10 \log \left( \frac{100}{50} \right) \end{aligned}$$

Thus  $C = 3$  and the APT  $G/T = -24$  dB.

Since both links are to be supported using common elements, the higher  $G/T$  must be chosen. Thus, we have the PCM  $G/T$  of  $-15.5$  dB. Therefore, the maximum required noise temperature is

$$\text{Temperature} = \text{antenna gain} - G/T = 25 - (-15.5) = 40.5 \text{ dB}$$

Since temperature in dB =  $10 \log T_{ok}$ , the links require a maximum total system noise temperature of  $11,200^\circ\text{K}$ .

## EXAMPLE 2

For Example 2, the 1698 MHz S-band link is to be supported at 15 degrees and above with a safety margin of 3 dB and the highest bit rate of 1.33 Mbps. The ground antenna is RHC with a gain of 40 dB.

From Figure 3-3, the required  $G/T$  is 9 dB. The correction factor is

$$C = CP - CI + 10 \log \left( \frac{\text{Bit Rate}}{0.66 \text{ Mbps}} \right)$$

where:

$$CP = 0$$

$CI = 0$ , because more than one link is radiating over this station.

$$\text{Bit Rate} = 1.33 \text{ Mbps}$$

$$C = 0 - 0 + 10 \log \left( \frac{1.33}{0.66} \right)$$

Thus  $C = 3$  and the corrected  $G/T$  is 12 dB.

Therefore, the noise temperature is

$$T = \text{antenna gain} - G/T = 40 - 12 = 28 \text{ dB}$$

Since temperature in dB =  $10 \log T_{ok}$ , the link requires a maximum total system noise temperature of  $630^\circ\text{K}$ .

A slightly different way of calculating the gain and temperature is shown in Appendix A.

A further note on noise temperature is required. In this section, we have calculated the total system noise temperature. The total system noise temperature is derived from:

$$T_{sys} = T_a + T_1 + \sum_{M=2}^M \frac{T_M}{G_{M-1}}$$

where:  $T_{sys}$  = total system noise temperature  
 $T_a$  = effective antenna temperature  
 $T_1$  = temperature of the preamplifier  
 $T_M$  = temperature of the succeeding  $M^{th}$  stage and  
 $G_{M-1}$  = gain preceeding the  $M^{th}$  stage

Use of this equation is shown in Section 5.

### 3.4 Dynamic Range

The final critical parameter necessary for designing a receiving station is the range of expected signal levels to be received and is called "dynamic range." The calculations to determine this parameter are shown in Appendix A and the results are shown graphically in Figures 3-4 and 3-5 for the VHF and S-band, respectively. The vertical axis of the figures has been defined as the RF power received at the input to the ground antenna.

In paragraph 3.3 above, the ground receiving antenna gain was determined. Therefore, the RF power received referenced to the preamp/paramp will be

$$RF_{PA} = RF_{AS} + G_A - L_A - CP$$

where:  $RF_{PA}$  = RF power referenced to the preamp/paramp  
 $RF_{AS}$  = RF power at antenna surface from the figures  
 $G_A$  = gain of antenna  
 $L_A$  = cable loss from antenna to preamp, and  
 $CP$  = cross polarization loss from paragraph 3.2

An example will illustrate how to use the figures.

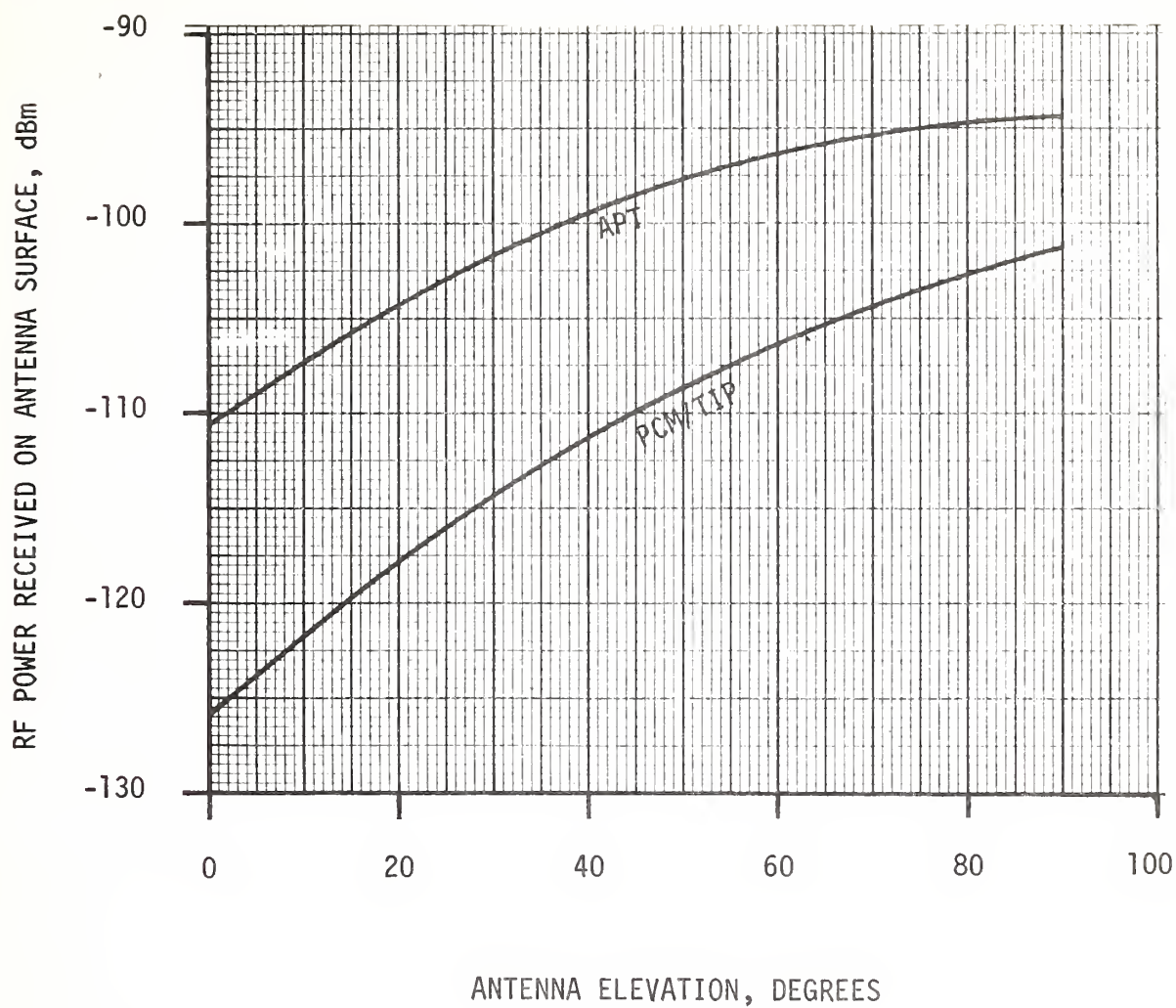


Figure 3-4.--VHF received power



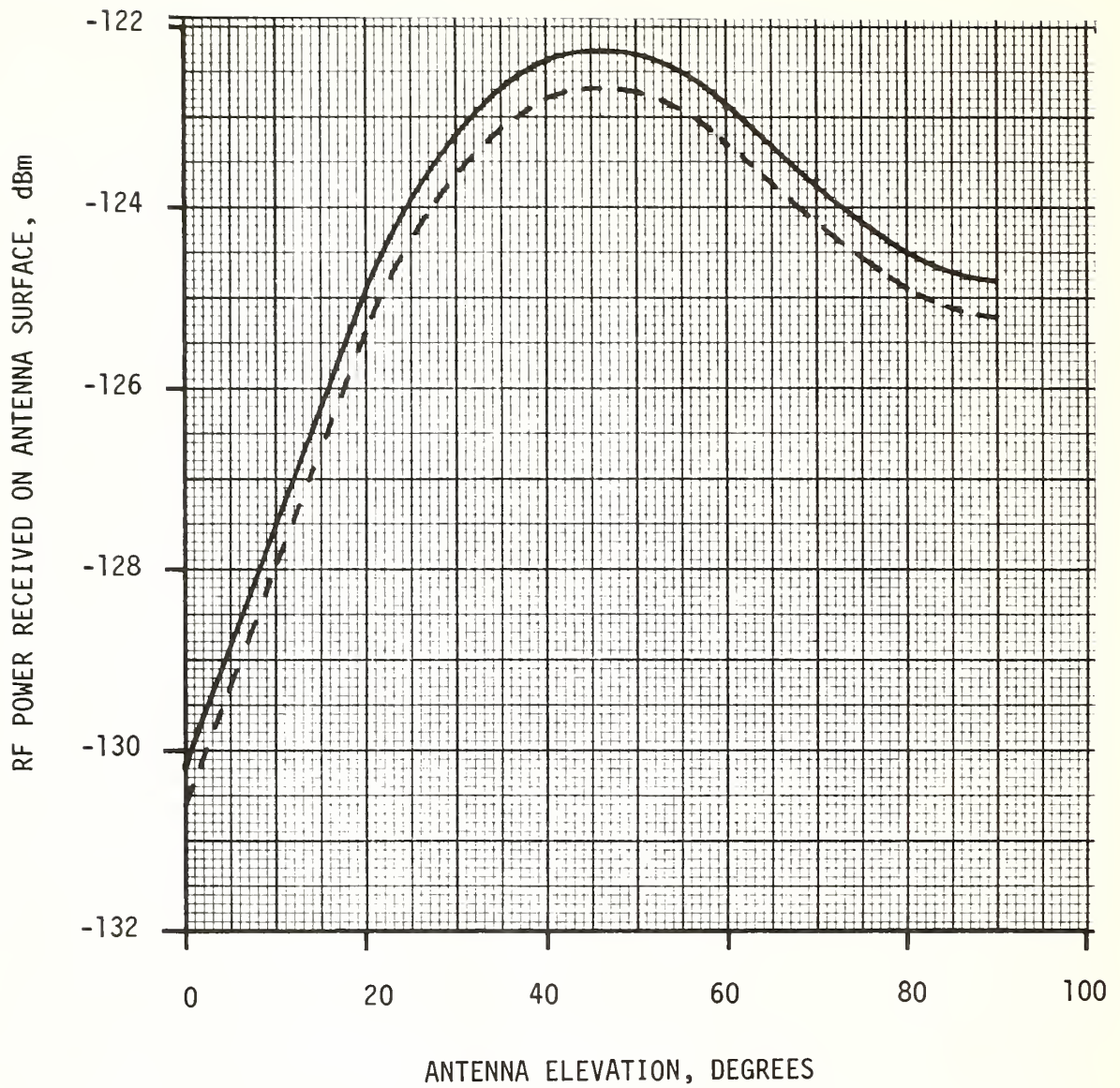


Figure 3-5.--S-band received power



## EXAMPLE

Using the same criteria shown in the VHF example in paragraph 3.3.3, the receive antenna gain is 25 dB. For this example,  $L_A$  will be 2 dB and CP = 3 dB for PCM and 0 dB for APT. From Figure 3 - 4 the following is determined:

<u>Link</u>	<u>15 Degree</u>	<u>90 Degree</u>
PCM	-119.5 dBm	-101.5 dBm
APT	-106 dBm	- 94.5 dBm

Therefore, using the above equation, we have a range of levels referenced to the preamp input of -99.5 dBm to -81.5 dBm for the PCM and -83 dBm to -71.5 dBm for the APT. For our example, we are supporting both links on one system. Thus, the total range will be -99.5 dBm to -71.5 dBm, referenced at the preamp input. If the maximum allowable specified signal level is -25 dBm at the receiver input, then the maximum allowable gain from preamp to receiver is 46.5 dB. If the overall gain is 46.5 dB, then the receiver range would be from -25 dBm to -53 dBm. This 46.5 dB overall gain would be used in the noise temperature calculations to select the individual gain/loss/temperature of each box in the system between the antenna and receiver.

As illustrated above, the example showed both VHF links were to be supported on a single system. Should different systems per link or only one link is to be supported, then the above procedure still applies except that only the single link numbers would be used. A word of caution to the designer is appropriate here. If the designer is only supporting the PCM link on VHF, he should still use the APT maximum received value in his calculations for dynamic range. This results from the fact that the TIROS-N APT transmission is on continuously and, if not accounted for in the PCM design, could saturate the receive system.



## SECTION 4 - S-BAND/VHF RECEIVING PARAMETERS

### 4.1 Introduction

This section describes and defines the critical parameters required in the receiving section of the ground system to electronically receive/demodulate the TIROS-N telemetry downlinks. These parameters are, for the most part, independent of thresholds, antenna gain, preamps, etc., which are determined by the pre-receiver system (antenna-to-receiver interface). Each parameter will be discussed for each link to which it applies.

### 4.2 Received Carrier Frequencies

In order to locate, receive, and demodulate the data downlinks, the RF carrier frequencies must be known. The TIROS-N spacecraft carries four frequencies in the VHF band and three frequencies in the S-band to transmit all the data.

For the VHF band, two of the four frequencies are prime while the remaining two are for redundant/backup purposes. To support the two data types (PCM (TIP) and APT) the following frequencies are used:

- a) PCM (TIP) - 136.77/137.77 MHz
- b) APT - 137.50/137.62 MHz

To support only one link (PCM (TIP) or APT), a minimum of one variable tuned receiver or one fixed tuned receiver, utilizing removable tuning heads, is required. For the fixed tuned receiver, two tuning heads would be needed. The receiver complement to support both links is twice that required for one link.

For the S-band, three frequencies (1698, 1702.5, and 1707 MHz) are used to transmit the four types of data. According to spacecraft design, all three RF links are identical as far as bandwidths, modulation types and indices, and transmitters. The only difference between the links is that the two outer frequencies (1698 and 1707 MHz) are right-hand circularly polarized while the center frequency (1702.5 MHz) is left-hand circularly polarized. A basic ground rule has been established to maintain that the HRPT data must be transmitted right-hand circularly polarized for normal operations. Thus, only the two outer frequencies are used; however, should transmitters fail, then HRPT may be transmitted on any of the available frequencies. The other data types (LAC/GAC/Stored TIP) may be transmitted either polarization sense.

As noted, to support all four S-band data types, only three receivers are required. These receivers should be identical in design and specifications to facilitate switching of data from one frequency to another. If only the HRPT data link is desired, then one receiver is required; however, this receiver must be tunable for all three frequencies.

#### 4.3 Received Intermediate Frequency (IF) Bandwidth

For purposes of transmitting data/information from a point in space to a point on the earth, a technique of modulating the baseband data/information onto a radio frequency (RF) carrier is used. In the process of modulation, the effective transmitted signal will normally occupy a range of frequencies from below to above the carrier frequency. At the transmission source, the range of frequencies is perturbed by the instabilities of the transmitter. The instability causes the carrier frequency plus the modulation components to randomly shift in frequency by small amounts. Thus, at the output of the transmitter source, the transmitted range of frequencies is determined by the modulation process and the source instabilities. For space applications, the vehicle or spacecraft containing the transmitter source is in motion around the earth. The ground observer is typically stationary on the earth's surface. Due to the relative motion between the spacecraft and the ground observer, the transmitted range of frequencies is further perturbed by the effect known as Doppler. Doppler shift is defined as the amount of frequency shift observed due to the relative motion. The ground receiver must be able to properly receive and demodulate the perturbed signal. The range of frequencies required in the ground receiver is called the "Received Intermediate Frequency (IF) Bandwidth." The IF bandwidth must be wide enough to accommodate the modulation effects, instabilities, and Doppler. Each is discussed in the following and the resultant minimum required IF bandwidth is presented.

From Section 2, the instability of the S-band and VHF transmitters has been specified as  $\pm 2 \times 10^{-5}$ . This corresponds to the following:

<u>Frequency (MHz)</u>	<u>Instability (kHz)</u>
137.50 APT	+ 2.750
137.62 APT	$\mp$ 2.7524
136.77 PCM	$\mp$ 2.7354
137.77 PCM	$\mp$ 2.7554
1698	$\mp$ 33.960
1702.5	$\mp$ 34.050
1707	$\mp$ 34.140

For purposes of calculating the worst case required IF bandwidth, the instability used will be  $\pm 34.140$  kHz for all the S-band links and  $\pm 2.7554$  for all the VHF links.

To determine the effect of Doppler, a worst case situation will be used. The Doppler effect is maximum to a ground observer when the spacecraft is at the horizon for a directly overhead pass. The Doppler shift, the amount of frequency change, is calculated in Appendix B. The results of the calculations are shown in Figure 4-1. For the S-band, the middle frequency was chosen for simplicity and to give the average value. The calculations will show that for the higher or lower S-band frequencies, the value of Doppler shift will change by an insignificant amount. For the same reason, only one VHF frequency is used. Thus, from the figure, the worst case Doppler shift occurs at the horizon and is  $\pm 37.5$  kHz for S-band and  $\pm 3.05$  kHz for VHF.

The last factor prior to the IF bandwidth determination is the effect of modulation. The calculations for received modulation bandwidths are shown in Appendix B. Using the appropriate values from Section 2 in the calculations yields:

<u>Frequency Band</u>	<u>Link</u>	<u>Modulation Type</u>	<u>Bit Rate</u>	<u>Code</u>	<u>Modulation Bandwidth</u>
VHF	APT	FM	-	-	38.784 kHz
VHF	PCM	PSK	8.32 kbps	S $\phi$	72.218 kHz
S-Band	Stored TIP	PSK	0.33 Mbps	S $\phi$	2.864 MHz
S-Band	HRPT	PSK	0.66 Mbps	S $\phi$	5.729 MHz
S-Band	LAC/GAC	PSK	1.33 Mbps	S $\phi$	11.544 MHz
S-Band	LAC/GAC	PSK	2.66 Mbps	NRZ	11.544 MHz

For the FM link,  $F_m = 2.4$  kHz and  $\Delta\phi = 7.08$  while for all PSK links  $\Delta\phi = 1.17$ .

The above table, however, assumes that no pre-modulation filtering exists on the spacecraft. If this were true, then serious interference would result from one channel to another in each band as shown by the choice of carrier frequencies and the above bandwidths. In order to reduce data interference, the spacecraft manufacturer has installed a pre-modulation filter prior to the transmitters. The S-band filters have a 3 dB cut-off frequency of about 2.4 MHz with a high attenuation above the cut-off frequency (on the order of 30-36 dB/octave). The VHF PCM filters have a maximum of 22 kHz 3 dB cut-off frequency and, again, a high attenuation above the cut-off frequency. This filtering, it is thought, will reduce the interference from one link to another without seriously degrading the data. This is a valid assumption since digital data is transmitted and that NRZ codes have the first zero crossing of the power spectral density at the bit rate while split phase codes occur at twice the bit rate. As a result, the transmitted bandwidths are approximately the following:



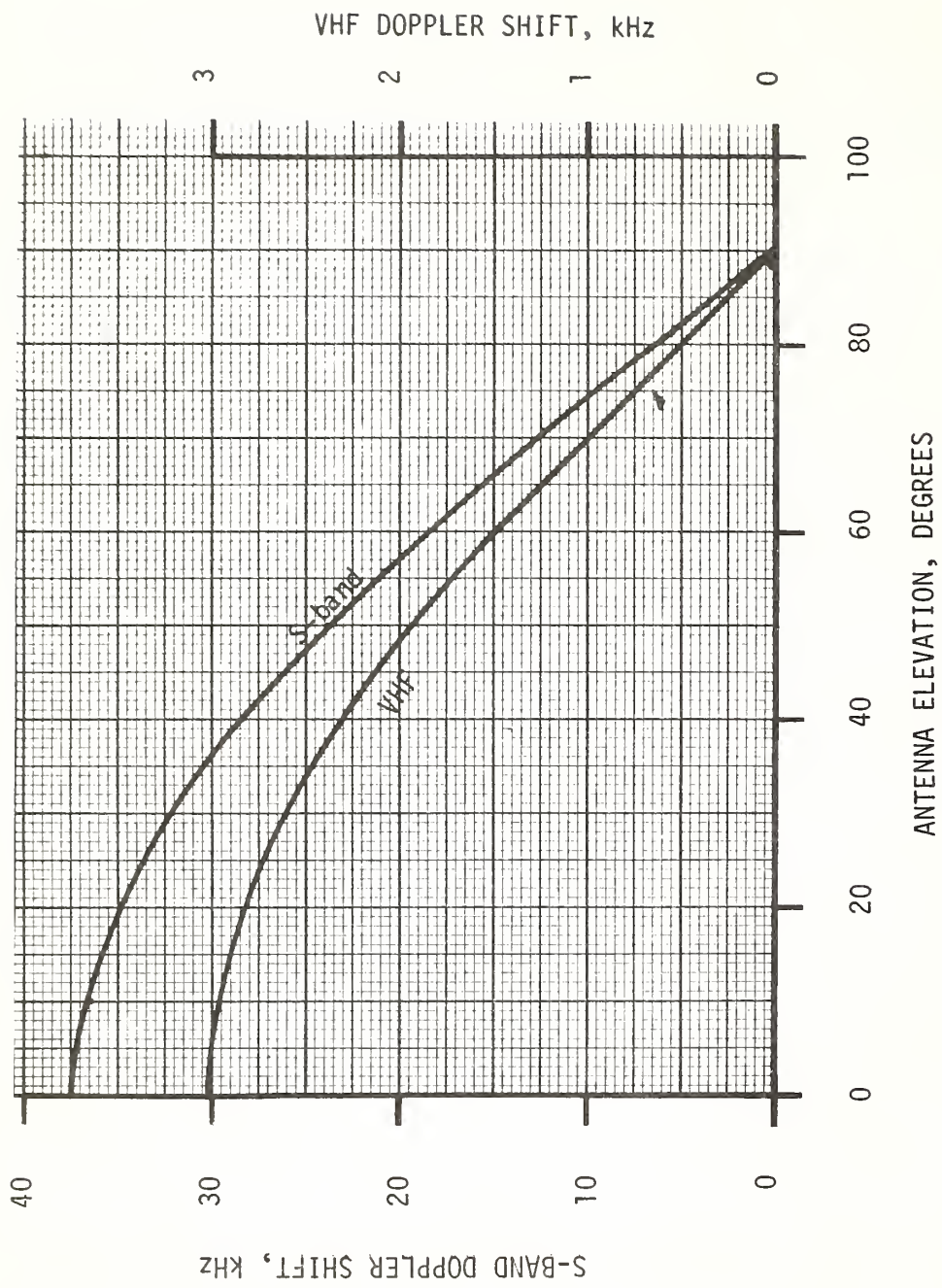


Figure 4-1.--Doppler Shift



<u>Link</u>	<u>Bit Rate</u>	<u>Code</u>	<u>Minimum Modulation Bandwidth</u>
APT	-	-	38.784 kHz
PCM(TIP)	8.32 kbps	S $\phi$	44.0 kHz
Stored TIP	0.33 Mbps	S $\phi$	2.864 MHz
HRPT	0.66 Mbps	S $\phi$	4.80 MHz
LAC/GAC	1.33 Mbps	S $\phi$	5.32 MHz
LAC/GAC	2.66 Mbps	NRZ	5.32 MHz

Placing the above values for modulation bandwidth, instability, and Doppler into the received bandwidth equation shown in Appendix B yields:

<u>Link</u>	<u>Bit Rate</u>	<u>Minimum IF Bandwidth</u>
APT	-	50.393 kHz
PCM(TIP)	8.32 kbps	55.611 kHz
Stored TIP	0.33 Mbps	3.007 MHz
HRPT	0.66 Mbps	4.943 MHz
LAC/GAC	1.33 Mbps	5.463 MHz
LAC/GAC	2.66 Mbps	5.463 MHz

Receiver IF bandwidths are normally rounded off to whole numbers for standardization purposes. Additionally, receiver bandwidths are typically specified at the -1 dB points. Because of standardization and the -1 dB point specifications, the following IF bandwidths are recommended as a minimum:

<u>Link</u>	<u>Minimum IF Bandwidth</u>
APT	50 kHz
PCM(TIP)	60 kHz*
Stored TIP	3 MHz
HRPT	5 MHz
LAC/GAC 1.33 Mbps	5 MHz
LAC/GAC 2.66 Mbps	5 MHz

\*If 60 kHz is not available, either 50 kHz or the next higher one above 60 kHz should be used.

#### 4.4 Demodulation Type

As mentioned previously, the process of transmitting baseband data/information from one source to another by use of carriers is called a modulation process. In order for the receiver to retrieve the information, it must demodulate the carrier. Three basic types of modulation/demodulation techniques are available to the system designer and are amplitude modulation (AM), frequency modulation (FM) and phase angle modulation. The phase angle modulation is commonly known as phase modulation (PM) or phase shift keying modulation (PSK).

For TIROS-N, the spacecraft manufacturer has chosen PM or PSK for all the S-band links and the VHF PCM (TIP) link. FM was chosen for the VHF APT link. Therefore, appropriate demodulators must be placed within the receiving ground station. The demodulator most often used for PM or PSK links is a phase-lock-loop tracking demodulator while, for the FM link, conventional frequency discriminator demodulators are normally used.

#### 4.5 Video Bandwidth

A low pass filter, commonly called a video or output filter, is normally placed on the output of the detection circuitry in a demodulator. The prime purpose of this filter is to "pass" the data/information with minimal distortion. The range of frequencies this filter will pass is called the video or output bandwidth.

For the APT link, it is expected that conventional frequency discriminators will be used. These discriminators normally use the same bandwidth on the output stage as the input stage. Therefore, for TIROS-N, the video bandwidth should be a minimum of 50 kHz. However, if conventional frequency discriminators with selectable outputs or a phase-locking frequency demodulator with selectable outputs is used, then the video bandwidth can be much narrower. The baseband data (1.6 kHz) is amplitude modulated onto a 2.4 kHz subcarrier. Therefore, it is necessary for the video bandwidth to pass at least the subcarrier plus the higher order subcarrier sideband. This means a bandwidth of at least 4.0 kHz. For safety and standardization purposes, a filter of at least 5.0 kHz should be used.

For the PCM links, standard phase-lock-loop demodulators would normally be used to retrieve the data from the phase modulated carrier. These demodulators usually contain selectable video filter bandwidths. The different data links are encoded into either NRZ or split phase signals. For NRZ signals, the first zero crossing in the power density spectrum occurs at the bit rate, while for split phase it occurs at twice the bit rate. In all cases, however, the video filter should be a low pass filter with an upper 3 dB cut-off frequency equal to at least the first zero crossing in the power density spectrum. Thus, the following minimum low pass filters could be used:

<u>Data Type</u>	<u>Bit Rate</u>	<u>Code</u>	<u>Low Pass Filter</u>
PCM (TIP)	8.32 kbps	S $\phi$	16.64 kHz
Stored TIP	0.33 Mbps	S $\phi$	0.66 MHz
HRPT	0.66 Mbps	S $\phi$	1.33 MHz
LAC/GAC	1.33 Mbps	S $\phi$	2.66 MHz
LAC/GAC	2.66 Mbps	NRZ	2.66 MHz

Standard bandwidths normally are 1.5, 3, 5, and 7.5, with multipliers of powers of 10. For conservative purposes, the video filter should be larger than required in order to pass the data with minimal distortion. Thus, recommended filters are:

<u>Data Type</u>	<u>Bit Rate</u>	<u>Filter</u>
PCM (TIP)	8.32 kbps	30 kHz
Stored TIP	0.33 Mbps	0.750 MHz
HRPT	0.66 Mbps	1.5 MHz
LAC/GAC	1.33 Mbps	3.0 MHz
LAC/GAC	2.66 Mbps	3.0 MHz

#### 4.6 Phase-Lock-Loop Tuning Range

For phase-lock-loop demodulators, a range of frequencies exists centered about the carrier in which the phase-lock-loop voltage controlled oscillator (VCO) can be varied. The purpose of this range is to enhance the operator's ability to acquire the moving spacecraft and, once acquired, to "track" the spacecraft frequency as the spacecraft passes over the station. This required range of frequencies is called "tuning range." To determine the range, two factors are normally considered: 1) frequency instability and offset of the source transmitter and 2) the Doppler effect. As mentioned previously, the amount of RF shift caused by the transmitters was  $\pm 34.140$  kHz for S-band and  $\pm 2.7554$  kHz for VHF while the maximum Doppler shift caused by the satellite motion was  $\pm 37.5$  kHz for S-band and  $\pm 3.05$  kHz for VHF. Thus, the total shift possible was  $\pm 71.640$  kHz for S-band and  $\pm 5.8054$  kHz for VHF. For conservative purposes, the VCO tuning range should be at least  $\pm 75$  kHz for S-band and  $\pm 6$  kHz for VHF centered about the carrier frequency.

#### 4.7 Phase-Lock-Loop Tracking Bandwidth

Once a phase-lock-loop has acquired and "locked" onto a carrier, the loop will follow the carrier utilizing a feedback error voltage technique. The error voltage is applied to the VCO to force the VCO to change frequency in the direction of decreasing error voltage. The error voltage is derived by phase comparing the incoming carrier with the referenced VCO output phase. A change in frequency of the VCO is related to the phase. Thus, the loop will

follow the incoming frequency/phase by forcing the VCO to be coherent with the input. In order to maintain this carrier phase lock and automatically track the input carrier frequency and its changes, the loop will act as though two filters exist. The first filter will be as broad as the input bandwidth and is used to pass the data/information. The second filter is a very narrow filter and is used to develop the error voltage needed to drive the VCO. In order to properly track the carrier, this second filter must reject all modulation components and respond only to the carrier and its changes. Thus, the second or tracking filter is usually on the order of 10 to 300 Hz single sided bandwidth. As mentioned previously, this tracking filter must be very narrow but also wide enough to pass the carrier changes and its rate of change. If this condition is not met, the loop will lose track resulting in loss of data.

The tracking filter essentially will "slide" with the VCO frequency as the loop tracks as long as the tuning range is not exceeded. As a result, very slow changes in the input are compensated for directly by the VCO and are usually not considered when choosing bandwidths. Slow changes are things like slow frequency drifts and Doppler shifts. However, for rapid changes, the width of the tracking filter will determine whether or not the loop will respond and remain locked. These rapid changes observed on the ground are caused by the spin rate of the spacecraft causing the antenna pattern to rapidly change gain, the rate of change of the Doppler shift, atmospheric disturbances which cause both power and frequency changes, etc.

Since TIROS-N is a three axis stabilized platform, no rapid changes in antenna gain are expected and will not be considered here. Additionally, atmospheric disturbances occur randomly and are of short duration; therefore, these also will not be considered here.

The basic parameter left to determine bandwidth is the rate of change of Doppler shift. The Doppler rate is calculated in Appendix B and the results plotted in Figure 4-2. Again, the middle of the frequency band is used to calculate the average value. Using the other frequencies would result in insignificant differences. From the figure, the maximum Doppler rate occurs when the spacecraft is directly overhead and is about 335 Hz/sec for S-band and 27 Hz/sec for VHF.

A common rule for relating tracking bandwidth to tracking rates is:

$$R = 2 BW^2$$

where

R = tracking rate

BW = one-sided tracking bandwidth

Solving, for TIROS N, for bandwidth yields:

$$BW = \left( \frac{R}{2} \right)^{\frac{1}{2}}$$



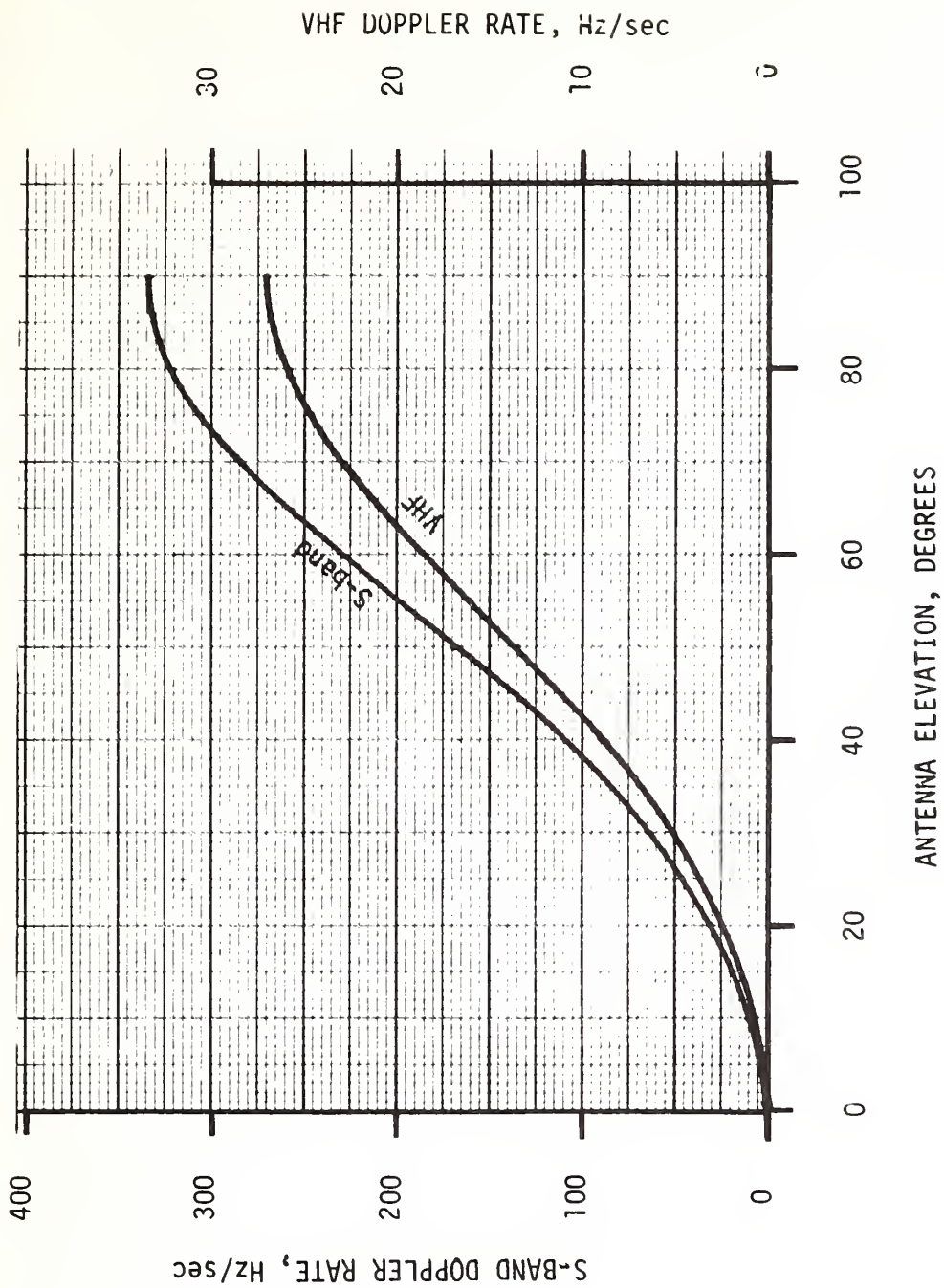


Figure 4-2.--Doppler rate

Putting the above Doppler rates into the equation for R yields a minimum required bandwidth of 12.942 Hz for S-band and 3.71 Hz for VHF. Bandwidths are normally specified as 3, 10, 30, 100, 300, 1000, and 3000 Hz. Therefore, the absolute minimum required one-sided tracking bandwidth is 10 Hz for VHF and 30 Hz for S-band. However, as mentioned previously, several other factors, although minor, were not considered. Additionally, since the ratios of bit rates to tracking bandwidths are very large (on the order of 250,000 to 800 for bit rates of 2.66 Mbps to 8.32 kbps), the bandwidth could be increased at least another two steps without seriously affecting the data. As a result, the recommended one-sided tracking bandwidth is 30 Hz for VHF and 100 Hz for S-band.

#### 4.8 Summary

Table 4-1 summarizes the recommended parameters for use in the ground receiving station for each link. Again, it should be emphasized that these parameters are threshold independent and are used strictly to receive and demodulate the downlinks. Discussions of thresholding parameters are located in Section 3. Parameters not listed on the table but which appear on the actual receivers should be set at the reader's discretion. Items such as these are AGC speeds, AC/DC coupling, etc. Some of these parameters can only be determined after experience with the orbiting spacecraft and are adjusted to provide the best data quality.



Table 4-1.--Receiving parameters for orbit mode.

ITEM	DATA TYPE					
	APT	PCM(TIP) 8.32 kbps S <sub>φ</sub>	Stored TIP 0.33 Mbps S <sub>φ</sub>	HRPT 0.66 Mbps S <sub>φ</sub>	LAC/GAC 1.33 Mbps S <sub>φ</sub>	LAC/GAC 2.66 Mbps NRZ
Frequency Band	VHF	VHF	S-Band	S-Band	S-Band	S-Band
Frequencies (MHz)	137.50 137.62	136.77 137.77	1698 1702.5 1707	1698* 1702.5 1707*	1698 1702.5 1707	1698 1702.5 1707
IF BW	50 kHz	60 kHz	3 MHz	5 MHz	5 MHz	5 MHz
Video BW	50 kHz or 5 kHz	30 kHz	0.750 MHz	1.5 MHz	3.0 MHz	3.0 MHz
Tuning Range	---	+5 kHz	+75 kHz	+75 kHz	+75 kHz	+75 kHz
Tracking BW (Hz) Single Sided	---	30	100	100	100	100

\*Normal frequencies, 1702.5 used only for failure modes.



## SECTION 5 - EXAMPLES

### 5.1 Introduction

This section presents examples of the method used to design ground stations for the TIROS-N spacecraft. Three particular examples are presented and are:

- 1) The APT only station
- 2) The HRPT only station, and
- 3) A station supporting multiple links.

The reader will be shown how the results of Sections 3 and 4 are applied to the design process. Many methods are available to the careful designer with each one dependent upon the initial given facts and conditions. In this section, only one approach will be given for each of the three station types. The presented approach, hopefully, will be typical of the average user's requirements. In the beginning of each example a discussion will be presented stating the initial conditions and assumptions used. Prior to presenting each example, some general words on a typical receiving station and noise temperatures will be given.

### 5.2 Receiving Stations and Noise Temperatures

A simplified RF receiving station is depicted in Figure 5-1. The major elements are the antennas, antenna control, RF front end, and the receiver. As shown, the input to the system is a radio frequency signal (data modulated onto a carrier) and the output is the data itself. Thus, the purpose of the system is to receive and demodulate the received signal to retrieve the data for further processing. A secondary purpose of the system is to be able to "follow" the received signal source through its movements. As for space applications, the data source is in orbit around the earth, thus necessitating an antenna capable of "tracking" the source. For this section, the "tracking" capability of the antenna itself will not be discussed.

The antenna, itself, is considered as the collection surface upon which the propagated electromagnetic wave is converted into the electrical energy required for data reception. Typically the antenna consists of strictly mechanical objects such as a parabolic dish, sub-reflectors, and feed elements, or just a simple dipole or dipole array elements. Receiving polarization type is typically determined by the arrangement of the antenna.

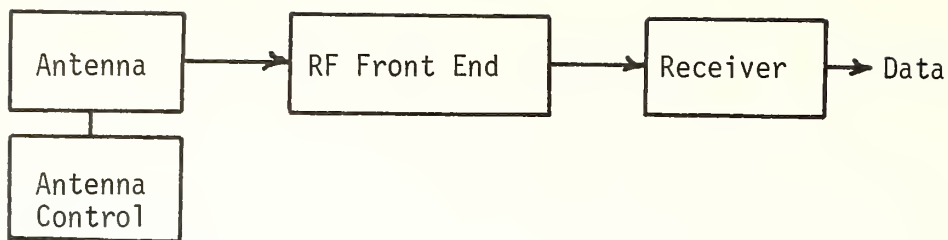


Figure 5-1.--Simplified receiving station

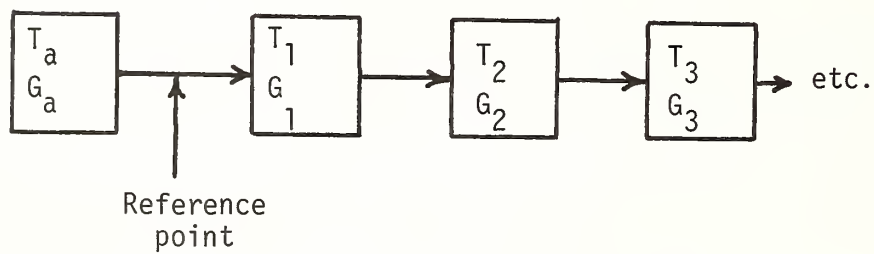


Figure 5-2.--Generalized system noise/gain configuration

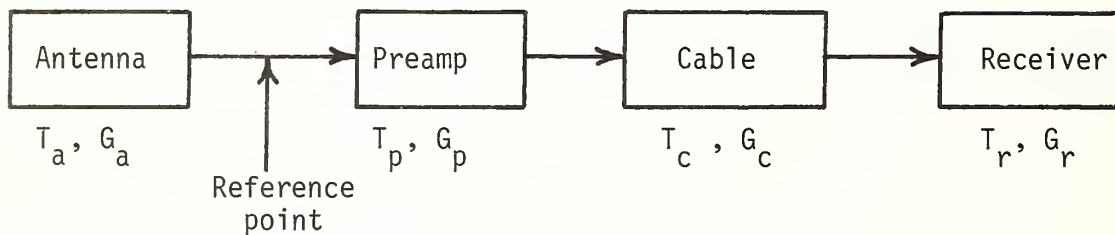


Figure 5-3.--System noise/gain configuration for the simplified receiving station

The RF front end's basic purpose is to receive the antenna output signal, amplify it, convert it to be compatible with a receiver, and relay it to the receiver. The front end in its simplest form consists only of a preamplifier and a length of cable. More complex systems contain preamplifiers, cable lengths, down or up converters, multicouplers, etc. In conjunction with the antenna gain/noise temperature and the receiver specifications, this part of the system defines the system threshold and overall system gain.

The receiver's main function is to receive the amplified and converted signal, demodulate it (remove the data from the carrier), recondition the data, and provide the data to the user at the required level. The receiver generally consists of IF amplifiers, demodulator circuits, data amplifiers, and AGC circuits. The AGC circuits try to maintain the output level constant with varying input levels.

The antenna control's job is to position the antenna at the desired "look angle." It generally consists of a command position, servo system, and encoder position. The command position tells where the antenna should look, the encoder system tells where it is looking, and the servo system compares the two and commands the antenna to move until the command and encoder positions agree. This system can be very simple or very complex.

Two parameters which primarily define a system's capability to receive and demodulate a signal in the presence of noise are the overall system gain and the system noise temperature. These two parameters are used by the designer to determine and specify each black box in the system. These parameters were determined in Section 3 and 4 and, in this section, are used to determine the box parameters in the examples. Figure 5-2 illustrates the general configuration for system gain and system noise temperature. The total system noise temperature for the system shown in Figure 5-2 is given by:

$$T_{\text{sys}} = T_a + T_1 + \sum_{M=2}^M \frac{T_m}{G_{M-1}} \quad (5-1)$$

Where:  $T_{\text{sys}}$  = total system noise temperature in °K  
 $T_a$  = effective noise temperature to left of the reference point in °K  
 $T_1$  = temperature of first box right of reference point, °K  
 $T_m$  = temperature of the  $M^{\text{th}}$  box right of the reference point, °K  
 $G_{M-1}$  = gain preceding the  $M^{\text{th}}$  box to the right of the reference point expressed as numerical ratios



The overall system gain shown in Figure 5-2 is given by:

$$G_O = \sum_{M=1}^M G_m \quad (5-2)$$

Where:  $G_O$  = overall system gain in dB's  
 $G_m$  = gain of  $M^{th}$  box in dB's

For the simplified receiving station, the system noise/gain configuration is shown in Figure 5-3. Applying Equation 5-1 to the figure results in the following total system noise temperature:

$$T_{sys} = T_a + T_p + \frac{T_c}{G_p} + \frac{T_r}{G_p G_c}$$

Where:  $T_a$  = effective noise temperature of the antenna in  $^{\circ}K$   
 $T_p, G_p$  = effective noise temperature and gain of the preamplifier in  $^{\circ}K$  and numerical ratio  
 $T_c, G_c$  = effective noise temperature and gain of the cable in  $^{\circ}K$  and numerical ratio  
 $T_r$  = effective noise temperature of the receiver in  $^{\circ}K$

Applying equation 5-2 to the figure and referencing to the receiver input yields:

$$G_O = G_a + G_p + G_c$$

Where:  $G_O$  = overall gain at receiver input in dB's  
 $G_a$  = antenna gain in dB's  
 $G_p$  = preamp gain in dB's  
 $G_c$  = gain/loss of the cable in dB's

As should be obvious, two parameters resulting in two equations are used to define the system boxes. Here is where the designer has the freedom to optimize and trade off among the various box parameters to select the best system. In this example, there are at least seven unknown variables, and only two equations. Thus, some other conditions must exist. Additionally the two equations are not independent since the gains of the boxes are present in both. The solution to this dilemma is for the designer to survey commercial equipment to see what best satisfies his needs. He then will use the selected box parameters in the equations. Additionally, he must make some choices or compromises on some of the equipment. In this way, he can narrow down the unknown variables to just a few and then develop a set of overall solutions, each meeting the system goals. With this set, he then can choose the most cost-effective.

The examples in this section will demonstrate the selection process.

Also obvious from the equations is that only temperatures and gains are specified. Normally, equipment is specified with either temperatures or noise figures for those equipment containing active components while passive devices are normally specified with a "loss" factor. This can be resolved easily by using the relationships:

For devices containing gain and specified by noise figures, we use

$$T = T_0 (N-1) \quad (5-3)$$

Where  $T$  = temperature of the box in  $^{\circ}\text{K}$

$T_0$  = reference temperature in  $^{\circ}\text{K}$ . For our use,  $T_0 = 290^{\circ}\text{K}$

$N$  = the Noise Figure ratio (numerical number).

For devices which contain a loss and no noise figure is specified (such as cables) we use

$$T = T_0 (1-\alpha) \quad (5-4)$$

Where  $T$  = temperature of the lossy element in  $^{\circ}\text{K}$

$T_0$  = reference temperature in  $^{\circ}\text{K}$ . For our use,  $T_0 = 290^{\circ}\text{K}$

$\alpha$  = the transmission line coefficient (numerical number derived from taking the anti-log of the dB's of loss). For example, a loss of 3 dB results in a  $\alpha$  of 0.5.

The noise received by a radio or radar system from natural external radiating sources has become increasingly important in recent years with the advent of "quieter" receivers and preamplifiers. The external noise now often sets the system performance limit. Since the discovery of cosmic noise, many studies have been made, resulting in data on which engineers base system performance estimates. However, the evaluation of all the contributing factors in a specific case is a difficult and complicated task. Often, engineers wish to make system performance calculations which take the "antenna noise,  $T_a$ " into account in a general way, without the necessity of a detailed investigation. The curve presented in this section (Figure 5-4) allows this to be done. For most applications, the accuracy provided by this curve will be adequate. It has become the accepted practice to represent the noise power received by an antenna from external radiating sources by an effective antenna noise temperature,  $T_a$ , shown in Figure 5-4. Use of this parameter will be shown in the remainder of this section.

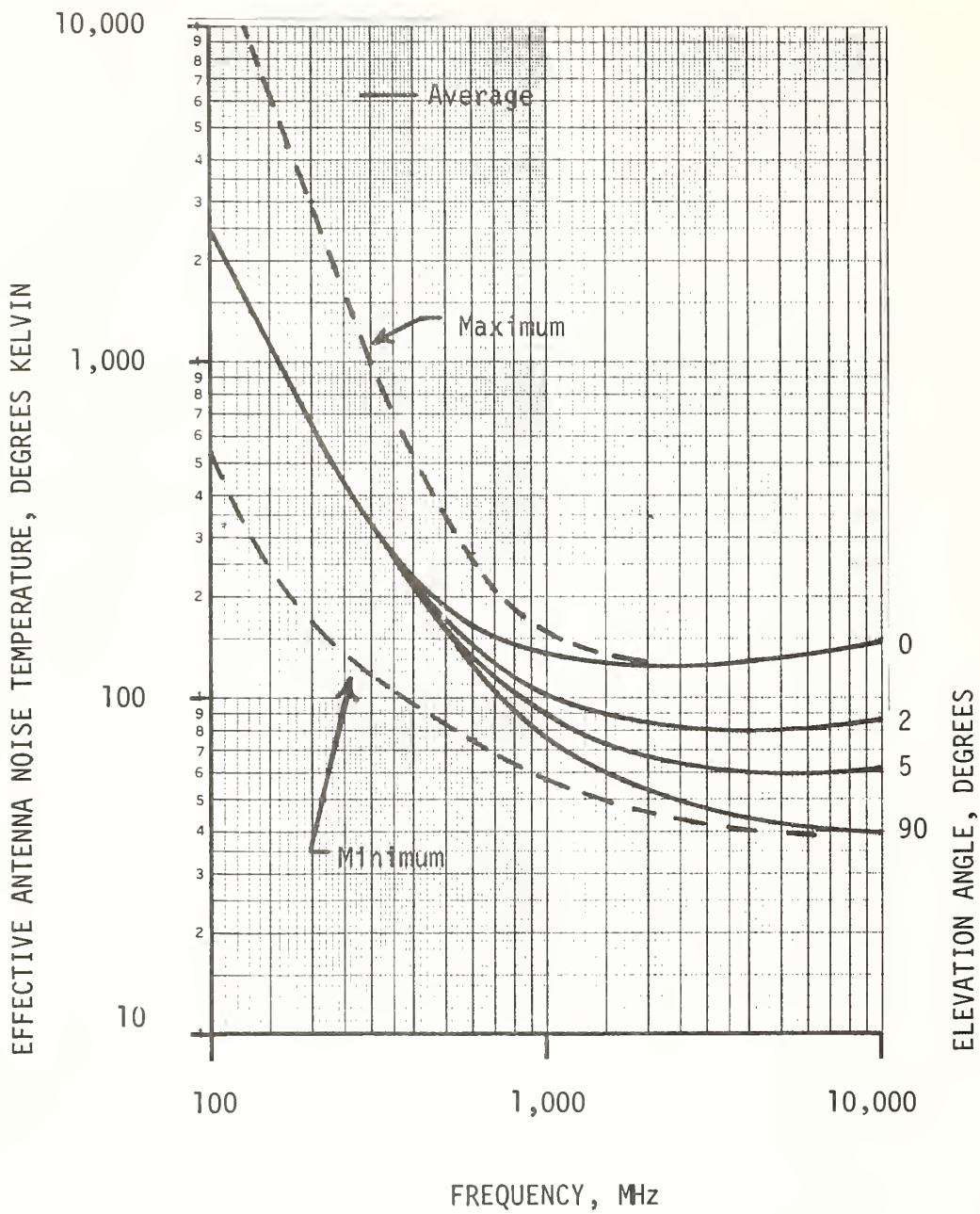


Figure 5-4.--Antenna noise temperature as a function of frequency

### 5.3 APT Only Station

The following paragraphs will discuss and define the required receiving station used to handle the TIROS-N APT link only. The station in its simplest form is shown in Figure 5-5.

#### 5.3.1 Initial Conditions and Assumptions

Several factors are required at the beginning of the design process as a starting point. Those items will be presented here. During the design process, other factors will need to be known and will be determined at that time. Again, emphasis is given that this is an example.

Initially, the user has stated that he would like data from 5 degree elevation angles and above and a safety margin of 6 dB above signal threshold at the minimum antenna elevation. The designer, to minimize system losses, has chosen a right-hand circularly polarized antenna since it matches the spacecraft antenna polarization. The antenna gain and thus the size has yet to be found. He has also already chosen a receiver for use on this link possessing the following capabilities:

<u>Parameter</u>	<u>Value</u>
Frequency range	VHF 136-138 MHz
Frequency tuning	Tunable over the band
IF bandwidths, kHz	10, 30, 50, 100, 300, 500, 1000
Video bandwidths, kHz	5, 15, 25, 50, 150, 250, 500
AGC speed, ms	3, 30, 300, 3000
Demodulations	AM, FM, PM
For FM, detection type	Discriminator
For AM, PM, detection type	Phase-lock-loop
Loop BW's, Hz	3, 10, 30, 100, 300
Tracking range, kHz	+6, +75, +150
Dynamic range	Thermal noise to -25 dBm
Noise figure	6 dB

The receiver is to be placed about 50 feet from the preamp. The cable specification is 4 dB of loss per 100 feet. Thus, this cable exhibits a 2 dB loss.



Figure 5-5.--APT only station



Figure 5-6.--HRPT only station

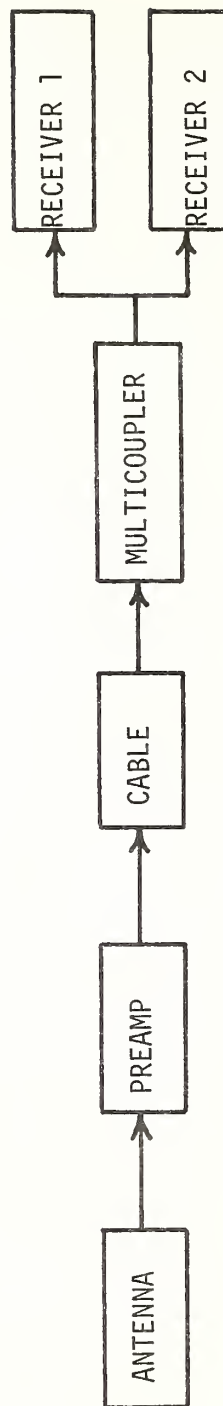


Figure 5-7.--Multiple Link VHF station



### 5.3.2 APT Receiving Parameters

The receiving parameters for the APT station can now be determined. Section 4 presents a discussion of each parameter and the recommended settings. Thus, the following set-up is used for the receiver:

<u>Parameter</u>	<u>Value</u>
Frequency band	VHF 136-138 MHz
Frequencies, MHz	137.50 or 137.62
IF BW, kHz	50
Video BW, kHz	5
Detection type	FM

The AGC speed is arbitrarily chosen as 30 ms. Experience in orbit will determine if this setting is adequate.

### 5.3.3 APT G/T Determination

The first step in defining the thresholding parameters is the determination of the G/T required. Section 3 discusses this parameter. From Figure 3-2 with 5 degrees minimum elevation angle and 6 dB safety margin, the required G/T is -24 dB. The correction factor for APT is

$$C = CP + 10 \text{ Log } \left( \frac{BW}{50 \text{ kHz}} \right)$$

Where: CP = cross polarization loss  
          = 0 since right-hand circular antennas are used  
      BW = RCVR IF = 50 kHz

Therefore, the correction factor is 0 and the corrected G/T is -24 dB.

### 5.3.4 APT Dynamic Range

The next step is to determine the expected signal level range for APT. Section 3 discusses this parameter and presents the results. From Figure 3-4, the range of levels at the antenna input is from -109 dBm to -94 dBm.

### 5.3.5 System Definition

The final steps are to determine the gains and temperatures of each box. Some items are already defined, such as the receiver and the cable. Others may, in this process, be arbitrarily chosen. However, the two determining items have been selected -- the G/T and the dynamic range -- and are used to determine the choices of the unknown variables. Using the G/T and the dynamic range as inputs to the design process will ensure that the final choices satisfy the TIROS-N and user requirements.

Starting with the overall gain equation, the variables begin to narrow down. Applying Equation 5-2 to the APT station (Figure 5-5) we have:

$$G_0 = (G_a - L_a - CP) + G_p + G_c$$

Where:  $G_0$  = overall gain at receiver input

$G_a$  = antenna gain

$L_a$  = loss between antenna elements and preamp.  $L_a$  is assumed to be 0 since we are using a negligible length of cable.

CP = Cross polarization loss = 0, antennas are matched

$G_p$  = preamp gain

$G_c$  = cable loss = -2 dB

The receiver maximum input is -25 dBm and the maximum expected signal at the antenna input is -94 dBm. Thus we have:

$$-94 + G_0 = -25$$

or

$$G_0 = 69 \text{ dB maximum}$$

Since this is a very large overall gain and no margin of safety would be present at the receiver, the overall gain can be reduced. Reducing it would ensure that the maximum spacecraft signal would not overload the receiver. A conservative margin would be 30 dB. Thus,  $G_0$  should be 39 dB. Placing this value into the overall gain equation yields:

$$39 = (G_a - 0 - 0) + G_p - 2$$

or

$$G_a + G_p = 41 \quad (5-5)$$

We now have a relationship between the antenna gain and preamp gain. Next we direct our attention to the system noise calculation. Applying equation

5-1 to the APT station (Figure 5-5) we have:

$$T_{sys} = T_a + T_p + \frac{T_c}{G_p} + \frac{T_r}{G_p G_c}$$

$T_r$ , the temperature of the receiver, is easily found from Equation 5-3 and the NF = 6 dB specification. Thus:

$$T_r = 290 (3.98 - 1) = 864.5^{\circ}\text{K}$$

$G_c$ , the cable gain/loss, is already known as - 2 dB or 0.631.  $T_c$ , the cable temperature, is also known using Equation 5-4 and  $\alpha = 0.631$ . Thus,  $T_c = 290 (1 - 0.631) = 107^{\circ}\text{K}$ .  $T_a$ , the effective antenna temperature, is found from Figure 5-4. For the VHF frequency it is about  $1500^{\circ}\text{K}$ .

Plugging the values into the above equation yields:

$$T_{sys} = 1500 + T_p + \frac{107}{G_p} + \frac{864.5}{G_p(0.631)}$$

or

$$T_{sys} = 1500 + T_p + \frac{1477}{G_p} \quad (5-6)$$

We now look at the G/T factor found previously. G/T is expressed from Section 3 and results in:

$$G/T = G_a - T_{sys} \text{ in dB's}$$

Thus we have for the APT:

$$-24 = G_a - T_{sys} \text{ in dB's} \quad (5-7)$$

We now have three equations (5-5, 5-6, and 5-7) with four unknowns ( $G_a$ ,  $T_{sys}$ ,  $T_p$  and  $G_p$ ). This, as the reader knows, does not resolve into one unique answer. Rather, a set of answers will result which satisfies these equations. Additionally, two equations are specified in dB's and the third in numerical ratios. One approach out of this dilemma is to use Equation 5-7 to develop a set of reasonable answers, select one of those answers, and apply it to Equations 5-5 and 5-6 to solve the remaining variables. Thus, the following table will satisfy Equation 5-7:

<u>G<sub>a</sub></u> <u>dB</u>	<u>T<sub>sys</sub></u> <u>dB</u>	<u>T<sub>sys</sub></u> <u>oK</u>
5	29	795
10	34	2,520
15	39	7,950
20	44	25,200
25	49	79,500

To select the proper choice, some considerations are needed. First, the  $T_{sys}$  must be greater than  $T_a$ . Thus, since  $T_a = 1500^{\circ}\text{K}$ , the first choice is automatically ruled out. Secondly, to keep costs down, one likes to keep the antenna gain low and the  $T_{sys}$  high. In the above table, two choices seem to be realistic -- the  $G_a$  of 10 and  $G_a$  of 15. Between these two choices, both practical,  $G_a$  of 10 would be chosen to keep antenna costs low and still have enough variance in calculating noise temperatures. As a result,  $G_a = 10$  dB and  $T_{sys} = 2,520^{\circ}\text{K}$ .

The gain of the preamp can now be determined from Equation 5-5. Therefore, the  $G_p$  is equal to 31 dB or 1,260.

The final parameter,  $T_p$ , can now be determined from Equation 5-6. Placing the above values into the equation yields:

$$2,520 = 1500 + T_p + \frac{1477}{1260}$$

or

$$T_p = 1019^{\circ}\text{K}$$

All parameters have now been determined. In summary, they are as follows:

<u>Parameter</u>	<u>Value</u>
G/T	-24 dB
Dynamic range at antenna input	-109dBm to -94 dBm
G <sub>a</sub>	10 dB
T <sub>sys</sub>	2,520 <sup>o</sup> K
G <sub>p</sub>	31 dB
T <sub>p</sub>	1019 <sup>o</sup> K max.
G <sub>c</sub>	-2 dB
NF of receiver	6 dB

## 5.4 HRPT Only Station

The following paragraphs will discuss and define the required receiving station used to handle only the TIROS-N S-band HRPT link. The station, simplified, is shown in Figure 5-6.

### 5.4.1 HRPT Initial Conditions and Assumptions

Initially the user has stated that he would want to support data from an elevation angle of five degrees and above with a safety margin of 3 dB at the minimum elevation angle. The designer, to minimize system losses, has decided to support only the right-hand circularly polarized spacecraft links. Thus, the ground antenna will also be polarized in the right-hand circular sense. The designer already has a 16-foot dish antenna having 36 dB of gain for his use. Additionally, a receiver has been chosen containing the following characteristics:

<u>Parameter</u>	<u>Value</u>
Frequency range	UHF 400-500 MHz
Frequency tuning	Tunable over the band
IF bandwidths, MHz	0.1, 0.3, 0.5, 1, 3, 5, 10
Video bandwidths, kHz	150, 250, 500, 1500, 2500, 5000
AGC speed, ms	3, 30, 300, 3000
Demodulators	AM, FM, PM
For FM, detection type	Discriminator
For AM, PM, detection type	Phase-lock-loop
Loop BW's, Hz	3, 10, 30, 100, 300
Tracking range, kHz	+6, +75, +150
Dynamic range	Thermal noise to -25 dBm
Noise figure	6 dB

Since the receiver range is 400-500 MHz and the TIROS-N link is S-band (1698-1707 MHz), a downconverter is required to translate the signal for use by the receiver. The downconverter local frequency is chosen to be 1250 MHz. Therefore, the S-band frequencies convert to receiver frequencies as follows:

<u>S-Band</u>	<u>Receiver</u>
1698	448
1707	457

The receiver is also to be placed about 50 feet from the antenna, paramp, and downconverter. The cable specification for loss is 6 dB per 100 feet. Thus, the cable loss is 3 dB.



### 5.4.2 HRPT Receiving Parameters

The receiving parameters for the HRPT station can now be found. From Section 4 and the above discussion, the following set-up is used for the receiver:

<u>Parameter</u>	<u>Value</u>
Frequency band	UHF, 400-500 MHz
Frequencies, MHz	448 or 457
IF BW, MHz	5
Video BW, kHz	1500
Detection type	PM
Loop BW, Hz	100
Tracking range, kHz	<u>+75</u>

The AGC speed is arbitrarily chosen as 30 ms.

### 5.4.3 HRPT G/T Determination

Determining the G/T is the first step for defining the system threshold. From Section 3, Figure 3-3, and the above conditions, the required G/T is 11.8 dB. The correction factor, for S-band, is:

$$C = CP - CI + 10 \text{ Log } \left( \frac{\text{Bit Rate}}{0.66 \text{ Mbps}} \right)$$

Where: CP = cross polarization loss = 0  
CI = correction to adjacent channel interference. Only one link is radiating over this station; therefore, CI = 3.8.

Bit Rate= 0.66 Mbps

Therefore, the correction factor is -3.8 and the corrected G/T is 8 dB.

### 5.4.4 HRPT Dynamic Range

Determining the expected signal level at the antenna input is the next step. From Section 3, Figure 3-5, and the initial conditions, the received signal level is -129.3 to -122.3 dBm.

### 5.4.5 System Definition

We now begin to define the gains/temperatures of each box. Starting with the overall gain equation the variables begin to narrow down. Applying Equation 5-2 to the HRPT station (Figure 5-6) we have:

$$G_o = (G_a - L_a - CP) + G_p + G_d + G_c$$

Where:  $G_o$  = overall gain at receiver input  
 $G_a$  = antenna gain = 36 dB  
 $L_a$  = loss between antenna elements and preamp.  
 $L_a$  is assumed to be 0 since negligible cable length exists.  
 $CP$  = cross polarization loss = 0, antennas are matched  
 $G_p$  = paramp gain  
 $G_d$  = downconverter gain  
 $G_c$  = cable loss = -3 dB

Thus,  $G_o = 33 + G_p + G_d$

The receiver maximum input is -25 dBm and the maximum expected signal level is -122 dBm. Now we have:

$$-122 + G_o = -25$$

or

$$G_o = 97 \text{ dB maximum}$$

Since this is a very large overall gain and no safety margin would be available at the receiver, the overall gain can be greatly reduced. Reducing it ensures that the receiver will not be overloaded. A conservative margin would be 30 dB. Thus,  $G_o$  should be 67 dB. Placing this value into the overall gain equation above and simplifying yields:

$$G_p + G_d = 34 \quad (5-8)$$

We now have a relationship between the paramp gain and the downconverter gain.

The next step is to determine the total system noise temperature. We can easily accomplish this using the  $G/T$  and  $G_a$  figures. Thus, from Section 3:

$$G/T = G_a - T_{sys}$$

Where:  $G/T = 8 \text{ dB}$   
 $G_a = 36$

Thus,  $T_{sys} = 28 \text{ dB or } 631^{\circ}\text{K}$ .

Applying Equation 5-1 to the HRPT station (Figure 5-6) we have

$$T_{sys} = T_a + T_p + \frac{T_d}{G_p} + \frac{T_c}{G_p G_d} + \frac{T_r}{G_p G_d G_c}$$

$T_r$ , the receiver temperature, is easily found from Equation 5-3 and the NF= 6 dB specification. Thus,  $T_r = 290 (3.98 - 1) = 864.5^{\circ}\text{K}$ .

$G_c$ , the cable loss, is already known as - 3 dB or 0.50.

$T_c$ , the cable temperature, is found using Equation 5-4 and  $\alpha = 0.50$ .  
Thus,  $T_c = 290 (1-0.50) = 145^{\circ}\text{K}$ .

$T_a$ , the effective antenna temperature, is found from Figure 5-4. For S-band it is about  $70^{\circ}\text{K}$  at 5 degrees.

Plugging the values into the above equation yields:

$$631 = 70 + T_p + \frac{T_d}{G_p} + \frac{145}{G_p G_d} + \frac{864.5}{G_p G_d (0.5)}$$

or

$$561 = T_p + \frac{T_d}{G_p} + \frac{1874}{G_p G_d} \quad (5-9)$$

We now have two equations (5-8 and 5-9) with four unknowns ( $T_p$ ,  $T_d$ ,  $G_p$ , and  $G_d$ ). Obviously, this will not resolve into a unique solution unless some further decisions are made. The first step will be to decide on a realistic value for one of the parameters. Then we will narrow the problem to two equations and three unknowns from which a set of solutions can be found. Then trade-offs and cost impacts will determine the best solution. Proceeding, the  $T_d$  parameter can be chosen to be typical. It is not unusual for commercial downconverters to be specified as having a noise figure of 5 dB or 3.16. Therefore, using Equation 5-3, the  $T_d$  will be  $627^{\circ}\text{K}$ . Placing it into Equation 5-9 yields:

$$561 = T_p + \frac{627}{G_p} + \frac{1874}{G_p G_d} \quad (5-10)$$

Now a set of solutions can be found from Equations 5-8 and 5-10. A further hint to help us is that it is preferable to have as much gain as possible in the front of the system in order to keep the noise temperature low. Thus,  $G_p > G_d$ . The following solution set can be found by selecting  $G_p$ 's:

$G_p$ dB	$G_p$ Ratio	$G_d$ dB	$G_d$ Ratio	$T_p$ oK
20	100	14	25.1	554
25	316	9	7.95	558
30	1000	4	2.51	559.6
34	2510	0	1	560

Any of the above solutions satisfy the system requirements. Cost, gain, and temperature trade-offs can now be performed to decide the optimum parameters. To keep costs down, gain probably should be distributed between the paramp and downconverter. A possible solution is the 20/14 gain split. Now all parameters have been defined and are summarized as follows:

<u>Parameter</u>	<u>Value</u>
G/T	8 dB
Dynamic range at antenna input	-129 dBm to -122 dBm
$T_{sys}$	6310K
$G_a$	36 dB
$G_p$	20 dB
$T_p$	5540K max.
$G_d$	14 dB
Noise figure, downconverter	5 dB
$G_c$	-3 dB
Noise figure, receiver	6 dB

## 5.5 Multiple Link Station

The following paragraphs discuss and define the receiving station used to support the TIROS-N VHF APT and PCM/TIP links. The station in a simplified form is shown in Figure 5-7.

### 5.5.1 Multiple Link Initial Conditions and Assumptions

Initially, the user has stated that he would like to support both links from an elevation angle of five degrees and above with a safety margin of 3 dB for both links at the minimum elevation angle. The designer has chosen the configuration shown in Figure 5-7. As illustrated, several of the components are common to both links. A multicoupler is used to split the signal to two receivers. The receivers are identical and can be tuned to either the APT or PCM signal. Since common elements are utilized, the designer realizes that he has to look at both links in his calculations and determine which link is critical. Then the system will develop from that link. Satisfying the critical link will mean that the other link will have much more margin than required. The antenna to be used is a 85-foot dish having a VHF gain of 27 dB and is right-hand circularly polarized. The cable length, already chosen, is 100 feet, with a loss of 4 dB per 100 feet. The multicoupler is a commercially built item having a noise figure of 5 dB and an overall effective gain from input to one output of 0 dB. The receivers have the following characteristics:

<u>Parameter</u>	<u>Value</u>
Frequency range	VHF 136-138 MHz
Frequency tuning	Tunable over the band
IF bandwidths, kHz	10,50,60,100,500,600,1000
Video bandwidths, kHz	5,25,30,50,250,300,500
AGC speed, ms	3, 30, 300, 3000
Demodulators	AM, FM, PM
For FM, detection type	Discriminator
For PM, AM, detection type	Phase-lock-loop
Loop BW, Hz	3, 10, 30, 100, 300
Tracking BW, kHz	+6, +75, +150
Dynamic range	Thermal noise to -25 dBm
Noise figure	6 dB

### 5.5.2 Multiple Link Receiving Parameters

The receiving parameters for the APT and PCM links can now be determined. From Section 4 and the above discussion, the following set-up is used:



<u>Parameter</u>	<u>APT</u>	<u>PCM</u>
Frequency band	VHF	VHF
Frequencies, MHz	137.50	136.77
	137.62	137.77
IF bandwidth, kHz	50	60
Video bandwidth,kHz	5	30
Detection type	FM	PM
Loop bandwidth, Hz	--	30
Tracking bandwidth,kHz	--	+6
AGC speed, ms	30	30

### 5.5.3 Multiple Link G/T Determination

The G/T for both links will now be determined. From Section 3, Figure 3-1, for VHF PCM the G/T required is -17.5 dB. Also from Section 3, Figure 3-2, for APT the required G/T is -27 dB. Both G/T's satisfy the initial conditions. The correction factor for VHF PCM is

$$C = CP$$

Where: CP = cross polarization loss = 3 dB.

Therefore, the correction factor is 3 dB and the corrected G/T is -14.5. The correction factor for APT is

$$C = CP + 10 \text{ Log } \left( \frac{BW}{50 \text{ kHz}} \right)$$

Where: CP = cross polarization loss = 0  
BW = 50 kHz

Therefore, for APT, the correction factor is 0 and the corrected G/T is -27 dB.

In order to proceed, a decision on G/T must be made. For this example, the station supports both links using common components. Therefore, to design, only one G/T can be used. It is necessary to select the more critical G/T. The higher G/T value is more critical. Thus, the PCM G/T of -14.5 dB will be used. The 3 dB safety margin will be satisfied for the PCM link whereas the APT link will have significantly more margin.

#### 5.5.4 Multiple Link Dynamic Range

The next step is to determine the expected range of signals for both links. From Section 3, Figure 3-4, the range of signals for APT is -109 dBm to -94.5 dBm and, for PCM, -124 dBm to -101.5 dBm.

#### 5.5.5 System Definition

The gains/temperatures for each box is now to be determined. Starting with the overall gain equation (5-2) and applying it to Figure 5-7 we have:

$$G_o = (G_a - L_a - CP) + G_p + G_c + G_m$$

Where:  $G_o$  = overall gain at receiver input  
 $G_a$  = antenna gain = 27 dB  
 $L_a$  = loss between antenna elements and preamp  
       $L_a = 0$  since the cable length is negligible.  
 $CP$  = cross polarization loss  
      = 0 for APT  
      = 3 for PCM  
 $G_p$  = preamp gain  
 $G_c$  = cable loss = -4dB  
 $G_m$  = multicoupler gain = 0 dB

Thus,  $G_o = 20 + G_p$ , PCM  
       $G_o = 23 + G_p$ , APT

The receiver maximum input is -25 dBm and the maximum signal level for APT is -94.5 dBm, and for PCM is -101.5 dBm. Since we are determining the maximum gain possible, we will use the link which contains the highest level. Thus, the APT link is used and we have

$$-94 + G_o = -25$$

or

$$G_o = 70 \text{ dB maximum}$$

If 70 dB were used for  $G_o$ , no safety margin would exist at the receiver. The gain can be greatly reduced to prevent receiver overloading. A conservative margin would be 30 dB. Therefore,  $G_o = 40$  dB. Placing this value into the overall gain equation determines the preamp gain. Thus:

$$40 = 23 + G_p$$

or

$$G_p = 17 \text{ dB}$$

Now all gains/losses are known. Only the temperatures have to be determined. The system noise temperature can be found readily by using the G/T and antenna gain figures:

$$G/T = G_a - T_{sys}$$

Where:  $G/T = -14.5$   
 $G_a = 27$

Thus,  $T_{sys} = 41.5$  dB or  $14,100^{\circ}\text{K}$ . Applying Equation 5-1 to Figure 5-7, we have:

$$T_{sys} = T_a + T_p + \frac{T_c}{G_p} + \frac{T_m}{G_p G_c} + \frac{T_r}{G_p G_c G_m}$$

$T_r$ , the receiver temperature, is easily found from Equation 5-3 and the NF = 6 dB specification. Thus,  $T_r = 290 (3.98 - 1) = 864.5^{\circ}\text{K}$ .

$G_m$ , the multicoupler gain, is already known to be 0 dB or 1.

$T_m$ , the multicoupler temperature, is found from Equation 5-3 and the NF = 5 dB specification. Thus,  $T_m = 290 (3.16 - 1) = 626^{\circ}\text{K}$ .

$G_c$ , the cable loss, is already known as -4dB or 0.398.

$T_c$ , the cable temperature, is found from Equation 5-4 and  $\alpha = 0.398$ .

Thus,  $T_c = 290 (1 - 0.398) = 174^{\circ}\text{K}$ .

$G_p$ , preamp gain, is 17 dB or 50.

$T_a$ , the antenna temperature, is found from Figure 5-4, and is  $1500^{\circ}\text{K}$  at five degrees elevation.

Therefore, the temperature equation simplifies to:

$$14,100 = 1500 + T_p + \frac{174}{50} + \frac{626}{50(0.398)} + \frac{864.5}{50(0.398)(1)}$$

or

$$T_p = 12,522$$

Now all parameters have been defined. In summary, they are:

<u>Parameter</u>	<u>Value</u>
G/T	-14.5 dB
Dynamic range at antenna input	-124 dBm to -94 dBm
$T_{sys}$	$14,100^{\circ}\text{K}$
$G_a$	27 dB
$G_p$	17 dB
$T_p$	$12,522^{\circ}\text{K}$ max.
$G_c$	-4 dB
$G_m$	0 dB
NF <sub>m</sub>	5 dB
NF <sub>r</sub>	6 dB



## APPENDIX A - VHF/S-BAND RF LINK CALCULATIONS

### A-1 Introduction

This appendix provides the calculations necessary for determining received power and system noise temperatures for the TIROS-N VHF/S-band data downlinks. Discussion of each topic and explanations of key items appear in the following paragraphs.

### A-2 Received Power

For purposes of determining the required ground station dynamic range and for post launch test and evaluation, a calculation must be made to determine the amount of RF power which will be received by the ground station. The following tables provide the necessary calculations:

- Table A-1, VHF PCM/TIP
- Table A-2, VHF APT
- Table A-3, S-band

Two general observations are necessary. The first is that, in some cases, the values are shown as minimum and maximum values. This range of values includes the expected tolerances for the spacecraft and the spacecraft-to-ground link. Utilizing these expected values ensures that the final system will operate between the two limits. The other observation is that these calculations are based on frequencies occurring in the middle of the VHF and S-band ranges. The higher and lower frequencies in these ranges will cause slight variations in the free space loss calculation. However, the variation is on the order of a few tenths of a dB and is considered insignificant.

As shown, the free space loss is considered a variable for all the tables. The free space loss is defined as the amount of RF attenuation which exists between the spacecraft and the ground antenna and varies as the spacecraft-to-ground antenna elevation angle changes. This value is easily calculated and is shown in Appendix B.

A second variable shown in the tables is the spacecraft antenna gain. For the VHF APT and the S-band spacecraft antenna, the gain varies as a function of the angle between the spacecraft axis and the ground "look angle." The antenna gain profiles for the VHF APT and S-band is shown in Section 2. The VHF PCM/TIP spacecraft antenna, however, has been specified as a dipole antenna having a gain of -6.0 dBi at an elevation angle of 5 degrees and a gain of +5.8 dBi at 90 degrees. Since the characteristics of the dipole antenna between angles of 5 and 90 degrees cannot be easily expressed, a linear approximation is used for simplicity and to achieve a smooth curve.

Table A-1.--VHF PCM/TIP RF power received on antenna surface as a function of antenna elevation

Parameter	Unit	Value
Transmitter Power	dBm	+30.0
Ant-Trans. Loss	dB	- 3.5
Antenna Gain	dBi	G
EIRP	dBm	26.5 + G
Free Space Loss	dB	L
Impinging RF Power	dBm	26.5 + G - L

- Notes: 1. The equation for L is in Appendix B.
2. G is calculated as a function of elevation angle and antenna specifications. At 5 degrees the gain is -6.0 dBi, while at 90 degrees it is +5.8 dBi. A linear equation is used to approximate the antenna gain at angles other than 5 or 90 degrees for the stabilized spacecraft. Thus,  $G = 0.139 \theta - 6.694$ .



Table A-2.--VHF APT RF power received on antenna surface  
as a function of antenna elevation

Parameter	Unit	Minimum	Maximum
Transmitter Power	dBm	+37.0	+37.4
Ant-Trans. Loss	dB	- 2.1	- 2.1
Antenna Gain	dBi	G	G
EIRP	dBm	34.9 + G	35.3 + G
Free Space Loss	dB	L	L
Impinging RF Power	dBm	34.9 + G - L	35.3 + G - L

Notes: 1. The equation for L is in Appendix B.

2. G is shown in Figure 2-4.

Table A-3.--S-band RF power received on antenna surface  
as a function of antenna elevation

Parameter	Unit	Minimum	Maximum
Transmitter Power	dBm	+38.0	+38.0
Ant-Trans. Loss	dB	- 2.8	- 2.8
Antenna Gain	dBi	G	G
EIRP	dBm	35.2 + G	35.2 + G - L
Free Space Loss	dB	L	L
Fading and Rain	dB	- 0.4	- 0.0
Impinging RF Power	dBm	34.8 + G - L	35.2 + G - L

Notes: 1. The equation For L is in Appendix B.

2. G is shown in Figure 2-8.

The end result of the tables is called the Impinging RF power and is defined as the amount of RF power that illuminates the ground antenna surface. More discussion of this parameter and its use is presented in Section 3 along with the graphical plot of power versus elevation angle.

### A-3 System Noise Temperature

When building a RF system, the system noise temperature must be chosen to satisfy a system threshold using predefined bit rates/receiver bandwidths, minimum antenna elevation angle, antenna gain, and a minimum margin above the threshold. For the TIROS-N VHF PCM/TIP and S-band data, the threshold has been defined as a data bit error rate probability of  $1 \times 10^{-6}$ . The threshold for the analog APT data is defined as a signal-to-noise ratio of at least 10 dB. However, this data is frequency modulated (FM) onto the VHF carrier requiring examination of the transmission format. A well-known fact is that FM systems require from about 9 to 12 dB carrier-to-noise ratio in the IF bandwidth for conventional discriminators. If the carrier-to-noise ratio is 12 dB or better, an improvement exists in the output signal-to-noise ratio. The amount of improvement is directly related to the modulation index. Thus, for threshold consideration, the required carrier-to-noise ratio is considered to be 12 dB. As long as the C/N is 12 or better, the S/N required by the user will be significantly exceeded.

#### A-3.1 Calculations

The following tables present the calculations for the TIROS-N data links:

- o Table A-4, VHF PCM/TIP
- o Table A-5, VHF APT
- o Table A-6, S-band

The variables used to determine system noise temperatures are free space loss which is directly related to elevation angle, ground antenna gain, required safety margin, and bit rate/receiver IF bandwidth. The calculations are based upon the minimum expected values. More discussion of system noise temperatures and its use is presented in Section 3 along with graphical plots.

#### A-3.2 How to Use Results

The table results are shown graphically in this appendix in Figures A-1.1 through A-3.5 for specific antenna elevation angles. The figure numbers have been defined as follows:

Figure A-X.Y

Where X defines the data type:

Table A-4.--System noise temperature calculation for the  
TIROS-N VHF downlink PCM/TIP data (8.32 kbps)

Parameter	Unit	Value
Transmitter Power	dBm	+30.0
Ant.-Trans. Loss	dB	- 3.5
Antenna Gain	dB <sub>i</sub>	SG
EIRP	dBm	26.5 + SG
Free Space Loss	dB	L
Ground Ant Pointing Loss	dB	- 0.2
Ground Antenna Gain	dB <sub>i</sub>	GG
Total Received Power	dBm	26.3 + SG + GG - L
Modulation Loss (67 ± 7.5 degrees)	dB	-1.3
Effective Received Signal	dBm	25.0 + SG + GG - L
Required Safety Margin	dB	M
Demod. Loss	dB	+ 3.0
Required $E_b/N_0$ ( $10^{-6}$ )	dB	+10.5
Required Received $E_b/N_0$	dB	13.5 + M
Total Noise	dBm	11.5 + SG + GG - L - M
Bit Rate BW	dB-Hz	10 Log $(8.32 \times 10^3) = 39.2$
Noise Spectral Density Required (NSD)	dBm/Hz	SG + GG - (L + M + 27.7)
Noise Temperature	°K	anti-Log $\left(\frac{198.6 + NSD}{10}\right)$
G/T	dB	GG - (198.6 + NSD)

Notes: 1. The equations for L and Modulation Loss are in Appendix B.

2. SG is calculated as a function of elevation angle and antenna specifications. At 5 degrees the gain is -6.0 dBi, while at 90 degrees (nadir) it is +5.8 dBi. A linear equation is used to approximate the antenna gain at angles other than 5 or 90. Thus,  $SG = 0.139 \theta - 6.694$ .

Table A-5.-- System noise temperature calculation for the  
TIROS-N VHF downlink APT data

Parameter	Unit	Value
Transmitter Power	dBm	+37.0
Ant-Trans. Loss	dB	- 2.1
Antenna Gain	dB	SG
EIRP	dBm	34.9 + SG
Free Space Loss	dB	L
Gnd. Ant. Pointing Error	dB	- 0.2
Ground Antenna Gain	dB	GG
Total Rcv'd RF Power	dBm	34.7 + SG + GG - L
Required Safety Margin	dB	M
Required Minimum C/N	dB	+12.0
Required Received C/N	dB	+12.0 + M
Total Noise	dBm	22.7 + SG + GG - (L+M)
Receiver IF	dB-Hz	10 Log IF
Noise Spectral Density Required (NSD)	dBm/Hz	22.7 + SG + GG - (L+M+10 Log IF)
Noise Temperature	°K	anti-Log ( $\frac{198.6 + NSD}{10}$ )
G/T	dB	GG - (198.6 + NSD)

- Notes: 1. The equation for L is in Appendix B.
2. SG is shown in Figure 2-4.
3. +12dB C/N in the IF is considered a threshold requirement for an FM system. The APT data user requires a minimum S/N of 10dB post detection. The 10dB S/N will be exceeded in an FM system as long as the C/N is 12dB or greater.

Table A-6.-- System noise temperature calculation for the TIROS-N  
S-band 1702.5 MHz downlink PCM data

Parameter	Unit	Value
Transmitter Power	dBm	+38.0
Ant-Trans. Loss	dB	- 2.8
Antenna Gain	dBi	SG
EIRP	dBm	35.2 + SG
Free Space Loss	dB	L
Fading and Rain	dB	- 0.4
Ground Antenna Gain	dBi	GG
Total Received Power	dBm	34.8 + SG + GG - L
Modulation Loss (67+7.5 degrees)	dB	- 1.3
Pre-Mod Filter Loss	dB	- 1.2
Adjacent Channel Inter- ference	dB	- 3.8
Effective Received Signal	dBm	28.5 + SG + GG - L
Required Safety Margin	dB	M
Demod. Loss	dB	+ 3.0
Required $E_b/N_0$ ( $10^{-6}$ )	dB	+10.5
Required Received $E_b/N_0$	dB	13.5 + M
Total Noise	dBm	15.0 + SG + GG - (L+M)
Bit Rate BW	dB-Hz	10 log BR
Noise Spectral Density Required (NSD)	dBm/Hz	15.0 + SG + GG - (L + M + 10 Log BR)
Noise Temperature	°K	Anti-Log ( $\frac{198.6 + NSD}{10}$ )
G/T	dB	GG - (198.6 + NSD)

Notes: 1. The equations for L and Modulation Loss are in Appendix B.

2. SG is shown in Figure 2-8.



<u>X</u>	<u>Data Type</u>
1	VHF PCM/TIP
2	VHF APT
3	S-band, bit rate = 0.66 Mbps

Y defines the elevation angle:

<u>Y</u>	<u>Elevation Angle, Degrees</u>
1	1
2	5
3	10
4	15
5	40

For example: Figure A-2.3 refers to the VHF APT taken at an elevation angle of 10 degrees.

The first step in choosing system noise temperature/gain is to decide the lowest elevation angle the user wishes to support for the interested downlink. This, plus the downlink characteristics, will determine a particular figure in this appendix. Normally, VHF antennas and preamps are designed to cover the frequency range of 136 to 138 MHz which satisfies both the PCM and APT links. If the user decides to support only one VHF link, then he can proceed directly to the calculations for that link. However, if both APT and PCM links are to be supported on the same system, then he need only calculate the PCM link. The reason is because the PCM link is a more critical link. Satisfying the PCM link will result in a more than sufficient link for the APT. For the S-band portion, if the user is expecting to support more than one link, then the highest bit rate should be utilized to determine the system noise temperature/gain. Satisfying this condition will satisfy the lower bit rates. We are now left with three variables; mainly, (1) antenna gain, (2) system noise temperature, and (3) safety margin. Compromising and tradeoffs are now possible to the designer for choosing the final system. If the designer is starting from scratch, then he should first decide on a safety margin. Next, he will alternate gain versus temperature from the figure until he finds an optimum solution in terms of cost and feasibility. If the user is starting from a given antenna gain, then he can only vary the safety margin until he finds a compatible noise temperature. The third possibility is starting from a predetermined noise temperature and varying gain and margin. However, this last strategy is a highly unlikely approach.

Example: An example will demonstrate the usefulness of the figures. The given facts are that both VHF PCM and VHF APT are to be supported above 5 degrees, antenna gain of 25 dB, and a receiver IF of 50 kHz for APT.

The first step is to locate the proper figures. For PCM the figure is A-1.2, while for APT it is A-2.2.



These figures show four possibilities as follows:

<u>Margin (dB)</u>	<u>PCM Temp. °K</u>	<u>APT Temp. °K</u>
9	4,700	40,000
6	9,400	80,000
3	18,800	160,000
0	37,600	320,000

As shown, the PCM link results in lower noise temperatures. Therefore, if both links are to be supported, then only the PCM link should be used. Designing for the PCM will result in a significant margin on the APT link. At this point in the design, cost and feasibility should enter the picture. As a guideline, cost increases as the antenna gain increases and as the temperature and/or margin decreases. In this example, the antenna gain was fixed, thus the trade-offs for cost are between the temperature and margin. In the VHF band a general rule of thumb for sky noise is on the order of 1500 °K (for S-band, it is about 70 °K). All the choices shown in the table for PCM are available for use. The logical choices are the 9 dB margin/4,700 °K and the 6 dB margin/9,400 °K. The 9 dB margin/4,700 °K choice is preferred since we have a good margin and the temperature is within reason. For this choice, 1500 °K is used for sky noise, leaving about 3200 °K to be used for the antenna, preamp, and individual box noise temperatures.

In Section 3, a correction factor was discussed which is applied to the calculations. Here again, the correction factor can be applied. In this case, however, the correction factor is applied to either the gain or the noise temperatures according to the following rules (assumes the correction factor is in the dB's):

1. If the noise temperature was used to determine the gain, then the antenna gain should be corrected as follows:

$$G_C = G + CF$$

where:

$G_C$  = corrected gain  
 $G$  = gain from figures  
 $CF$  = correction factor

2. If the gain was used to determine the temperature, then the temperature should be corrected as follows:

$$T_C = T * \left( \text{anti-log } \frac{CF}{10} \right)$$

where:

$T_c$  = corrected temperature

$T$  = Temperature from figures

CF = correction factor

\* = multiplication

Thus, if CF is +3 dB then the gain is 3 dB higher or the temperature is twice that shown on the figures.

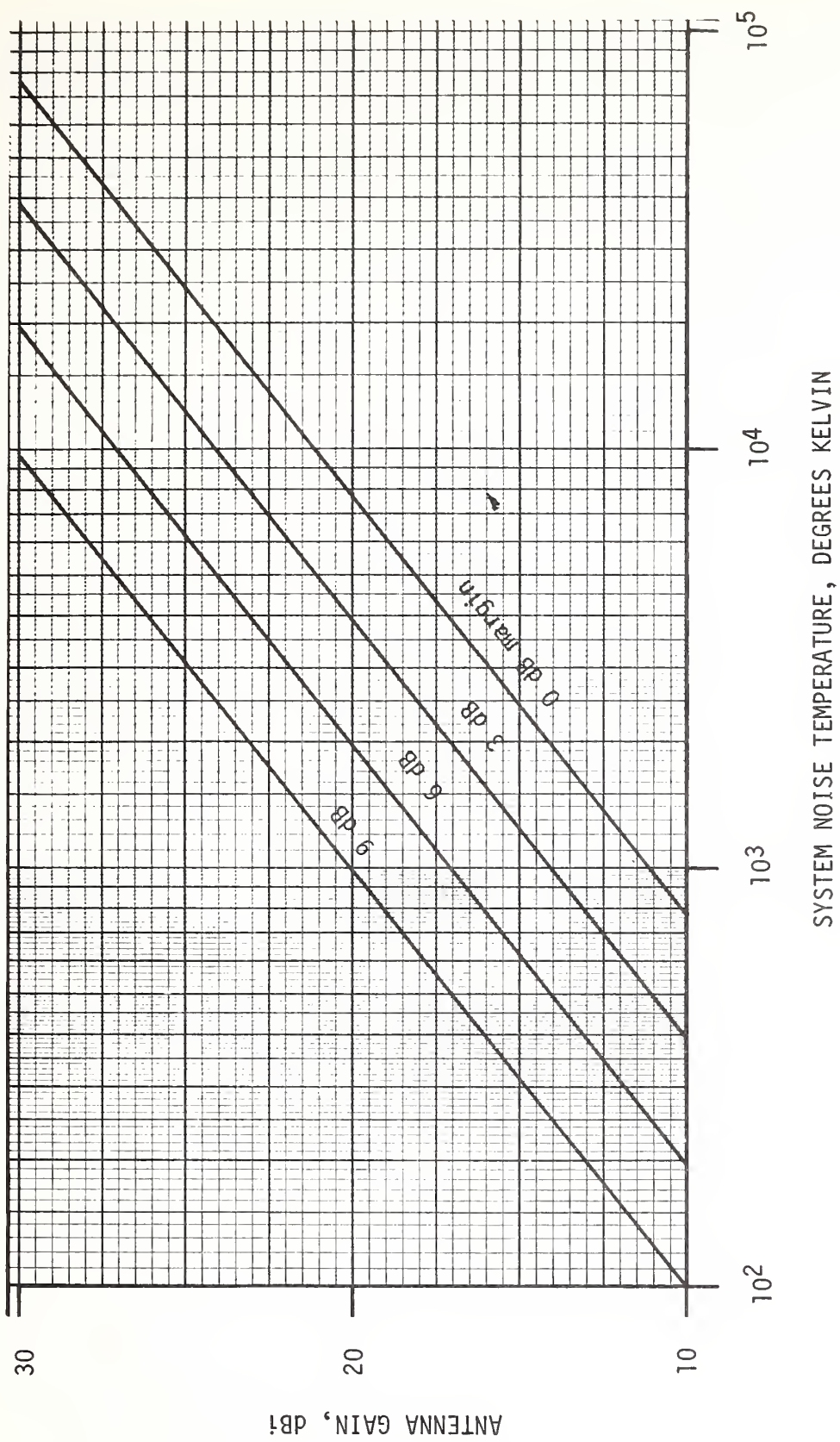


Figure A-1.1.--VHF PCM/TIP  
1 degree elevation

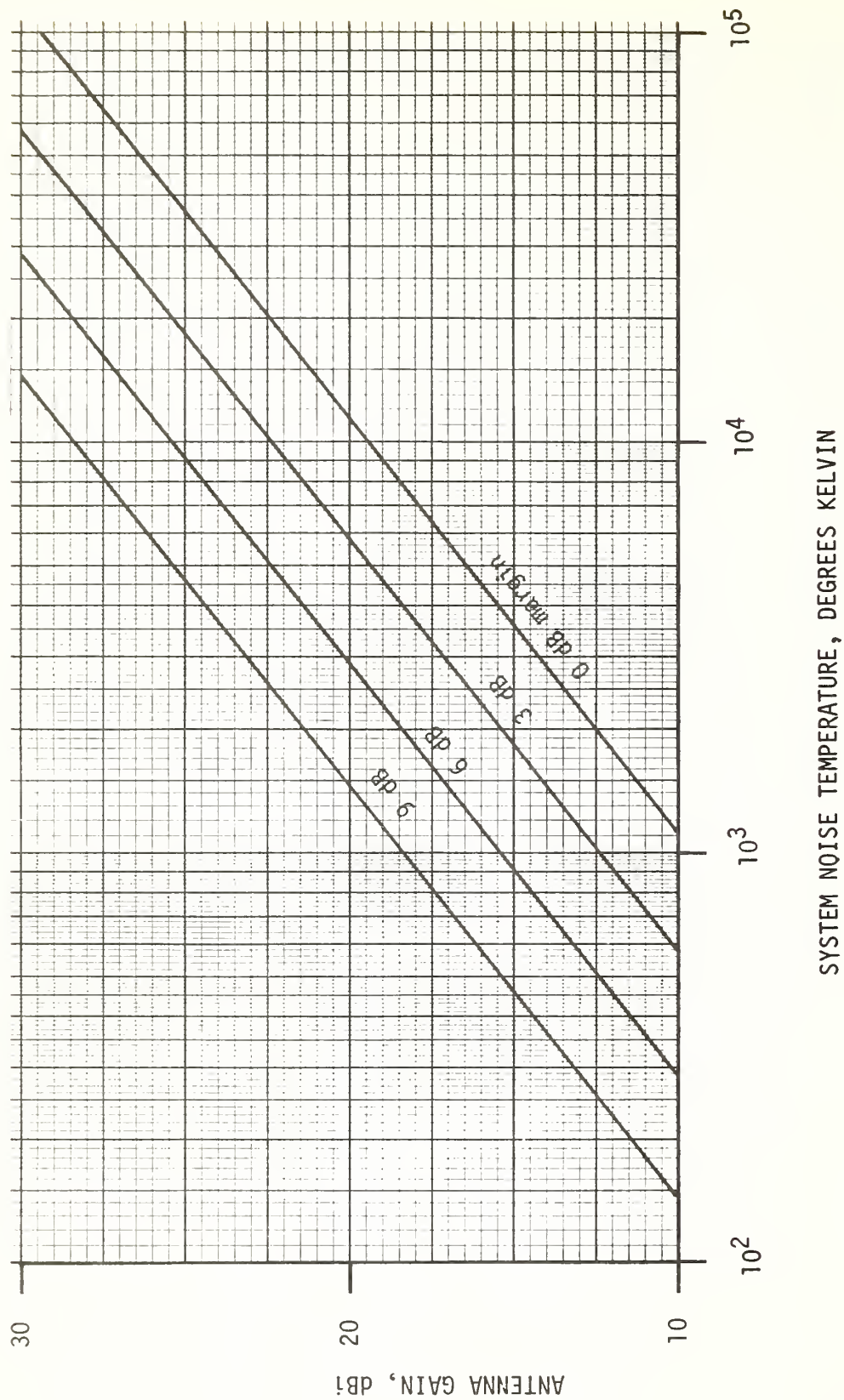


Figure A-1.2.--VHF PCM/TIP  
5 degree elevation

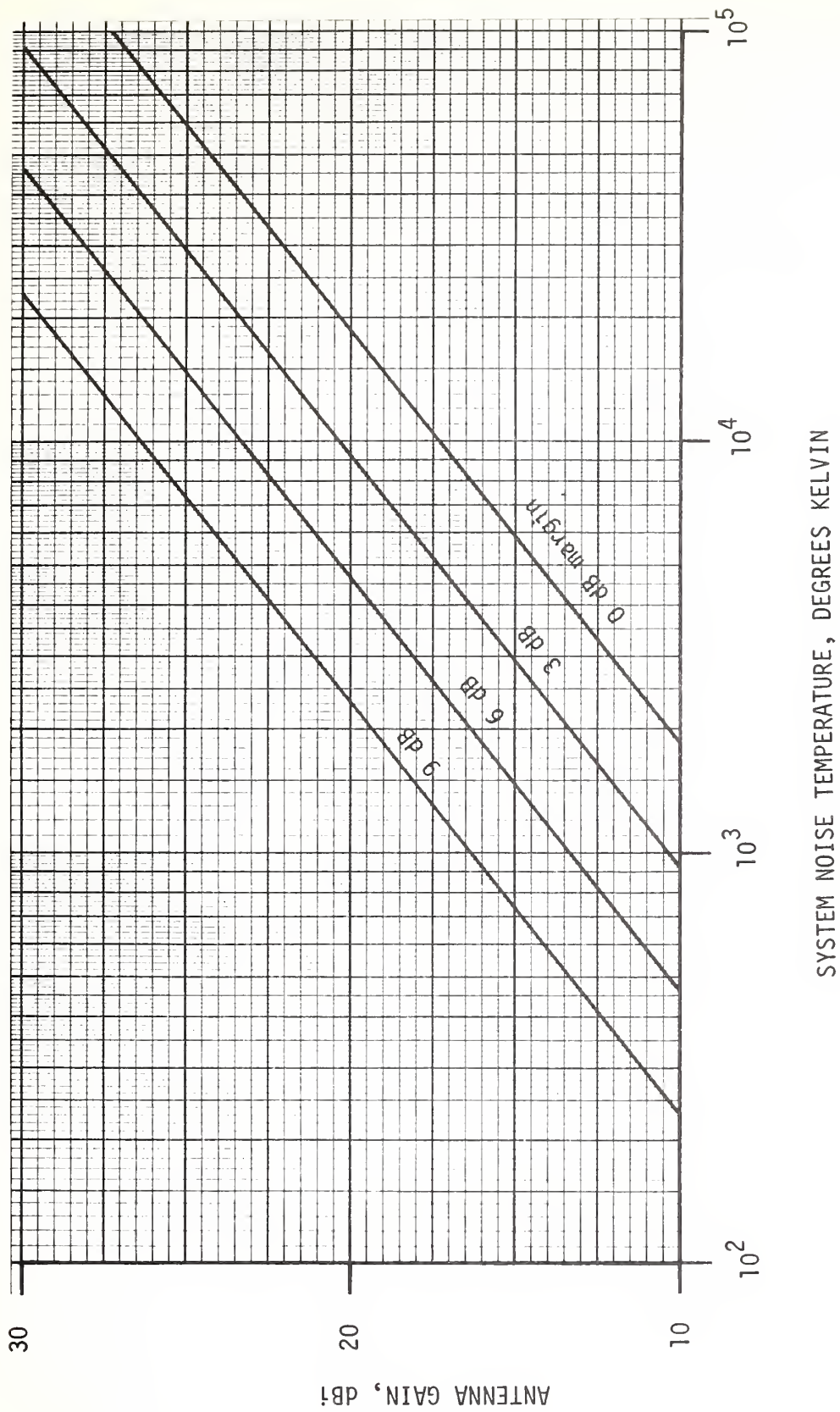


Figure A-1.3.--VHF PCM/TIP  
10 degree elevation



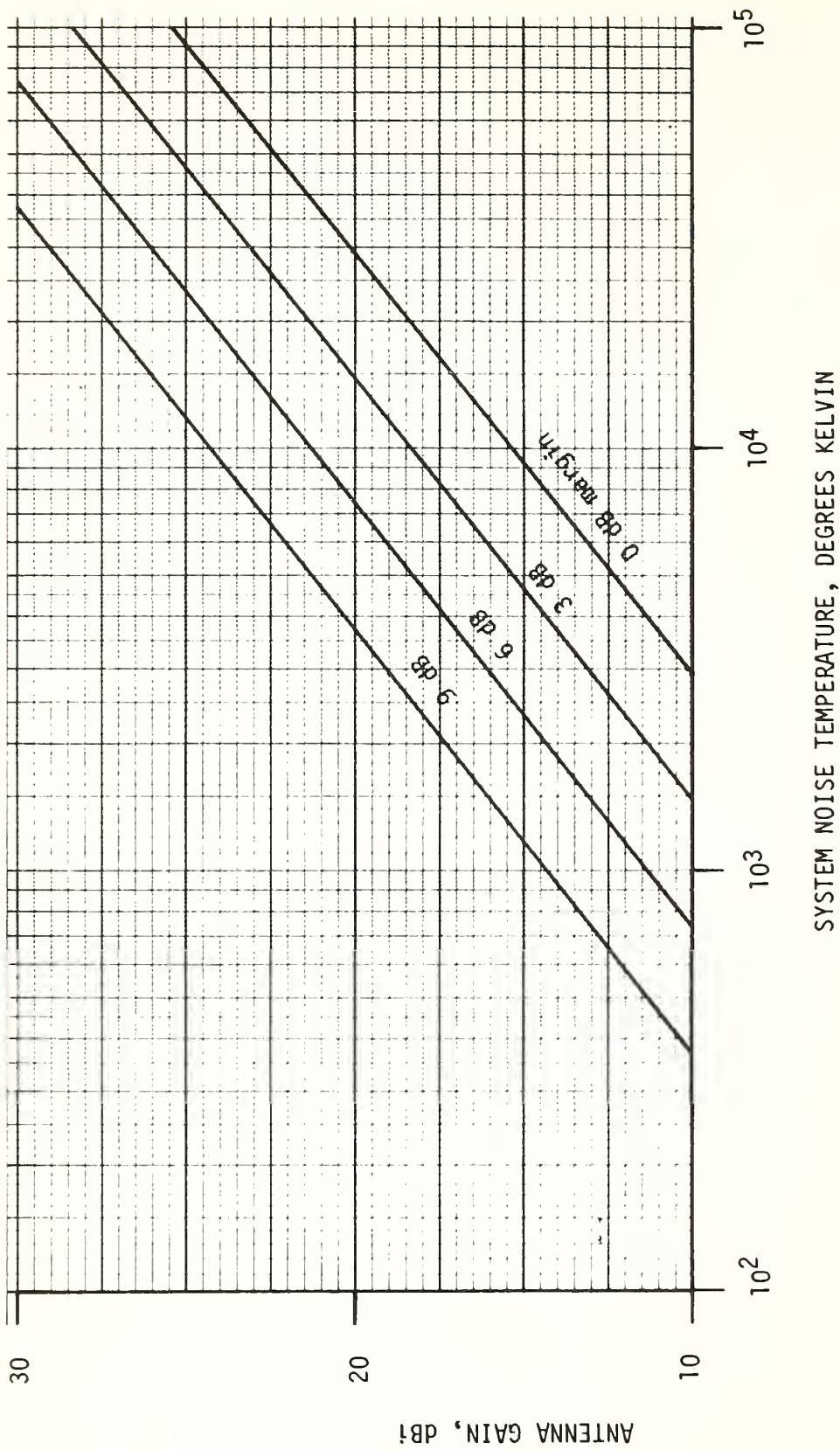
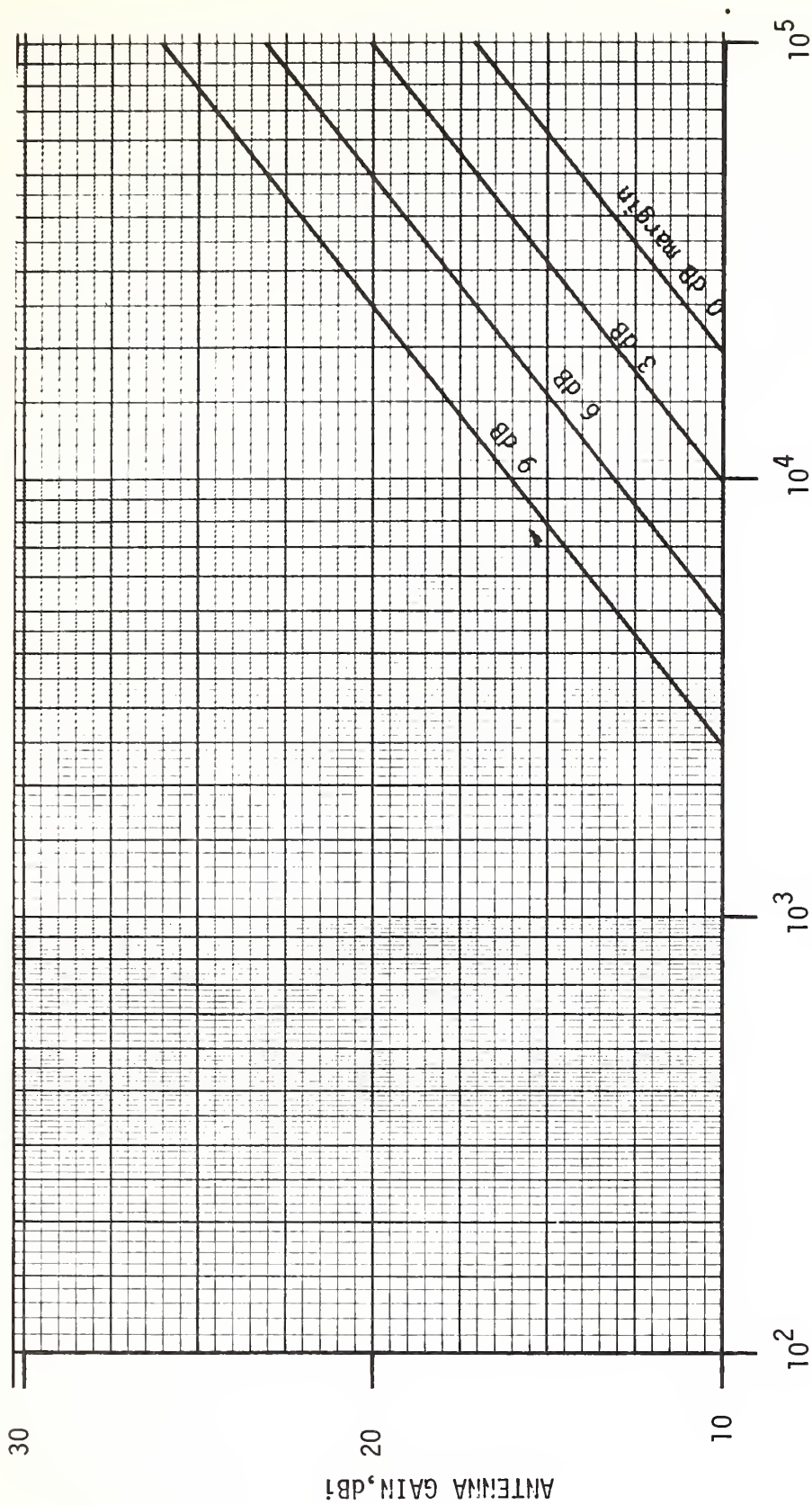


Figure A-1.4.--VHF PCM/TIP  
15 degree elevation





SYSTEM NOISE TEMPERATURE, DEGREES KELVIN

Figure A-1.5, --VHF PCM/TIP  
40 degree elevation

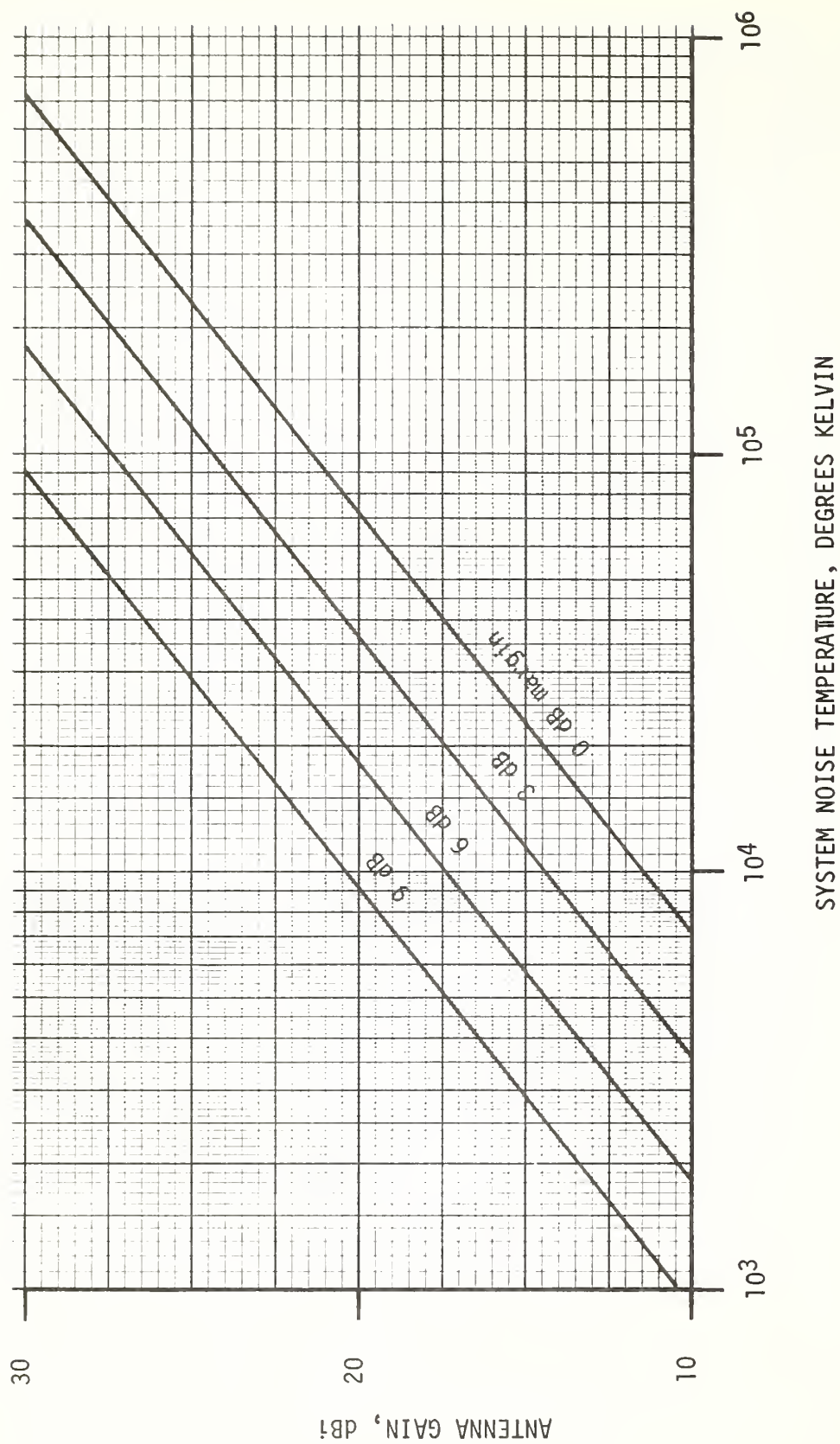


Figure A-2.1.--VHF APT, RCVR IF = 50 kHz  
1 degree elevation

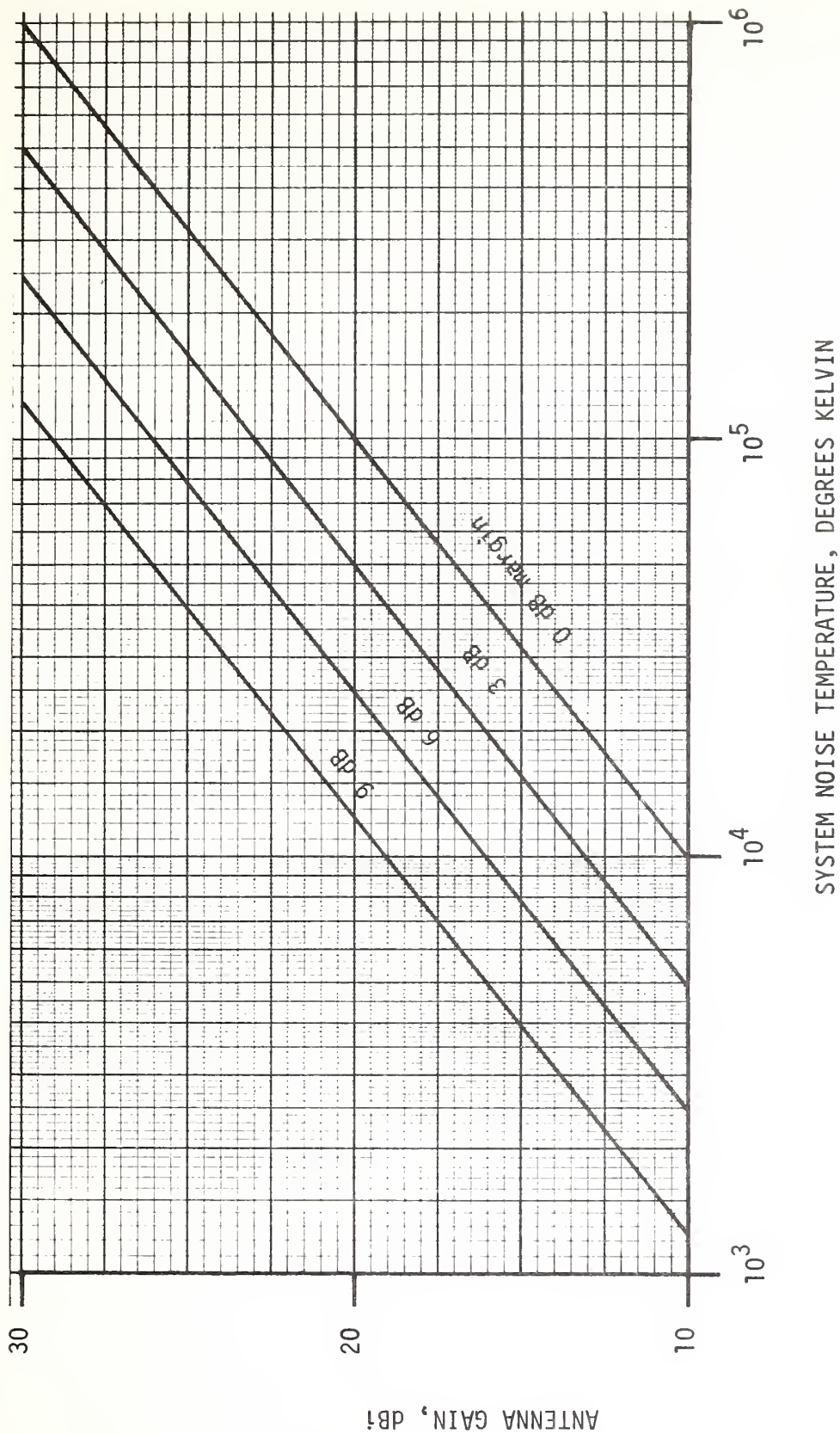


Figure A-2.2.--VHF APT, RCVR IF = 50 kHz  
5 degree elevation

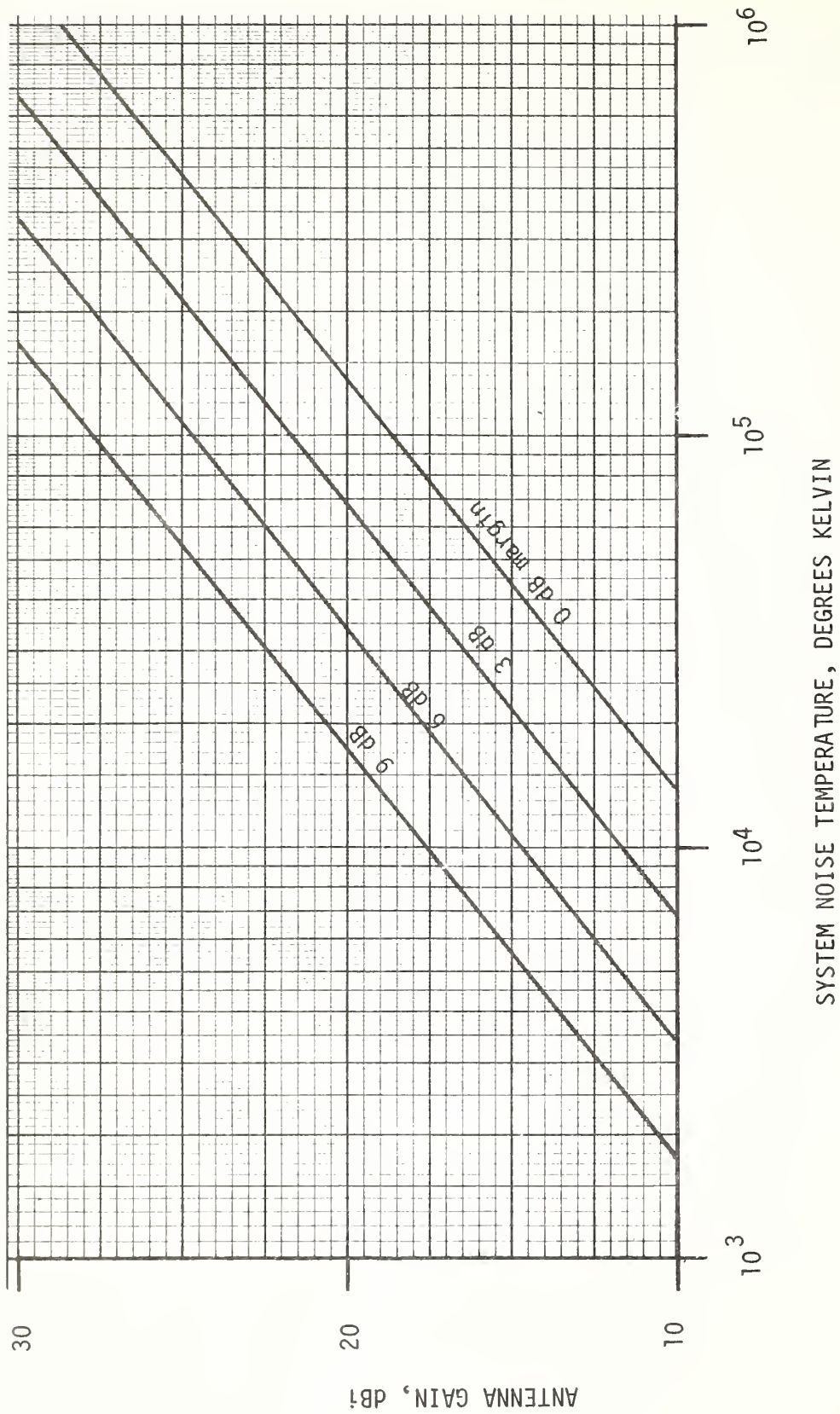
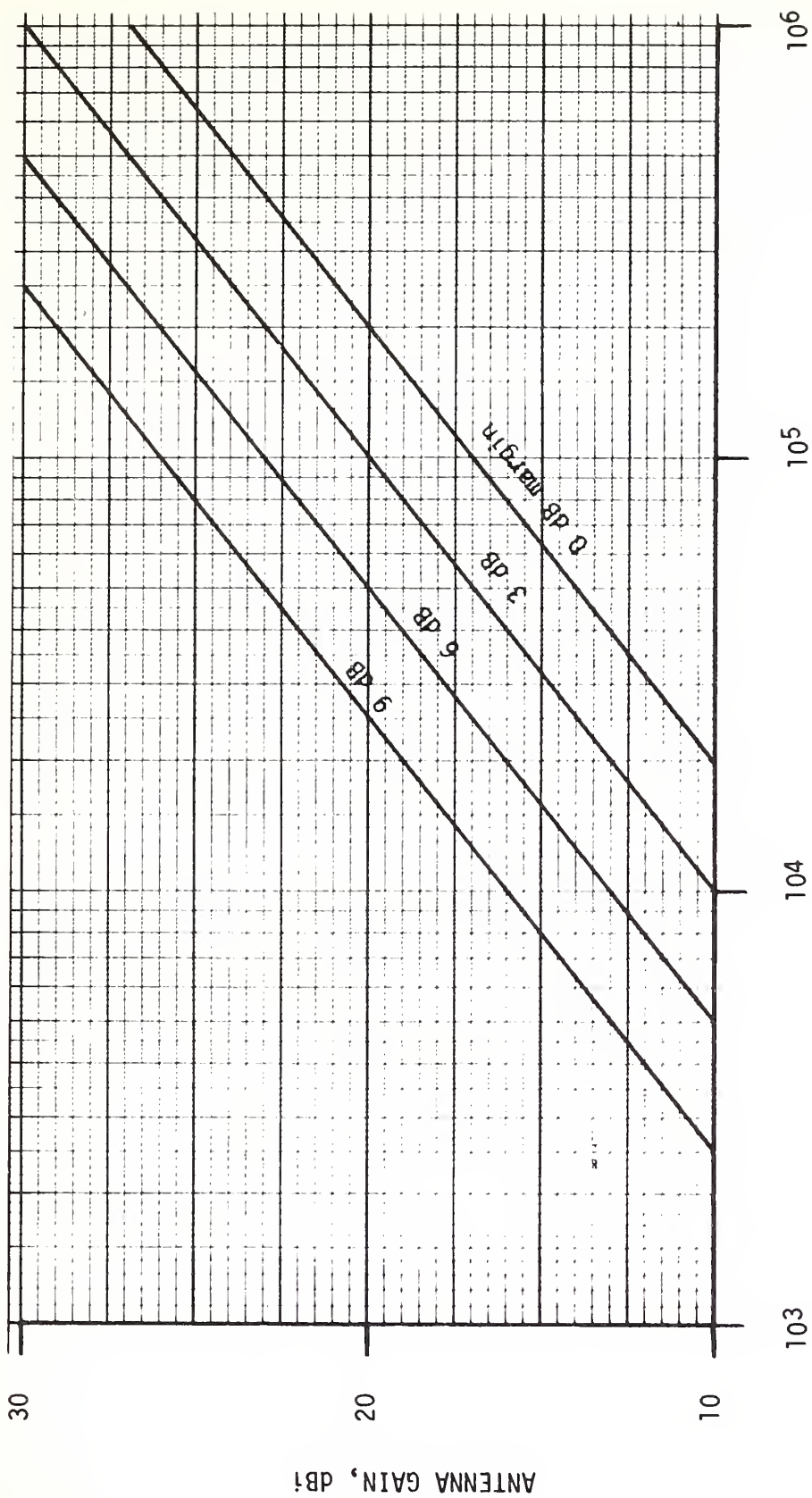


Figure A-2.3.--VHF APT, RCVR IF = 50 kHz  
10 degree elevation





SYSTEM NOISE TEMPERATURE, DEGREES KELVIN

Figure A-2.4. --VHF APT, RCVR IF = 50 kHz  
15 degree elevation

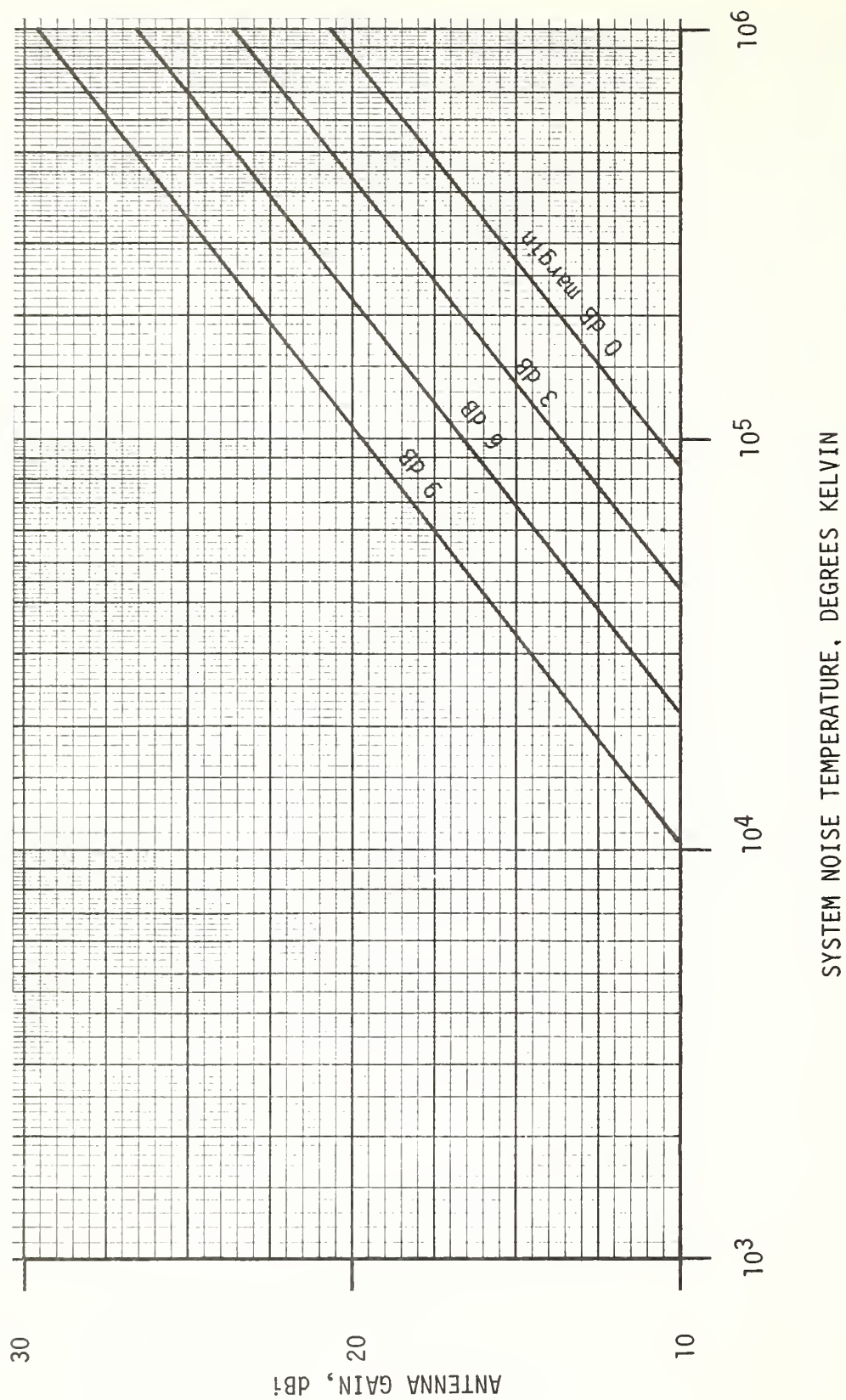
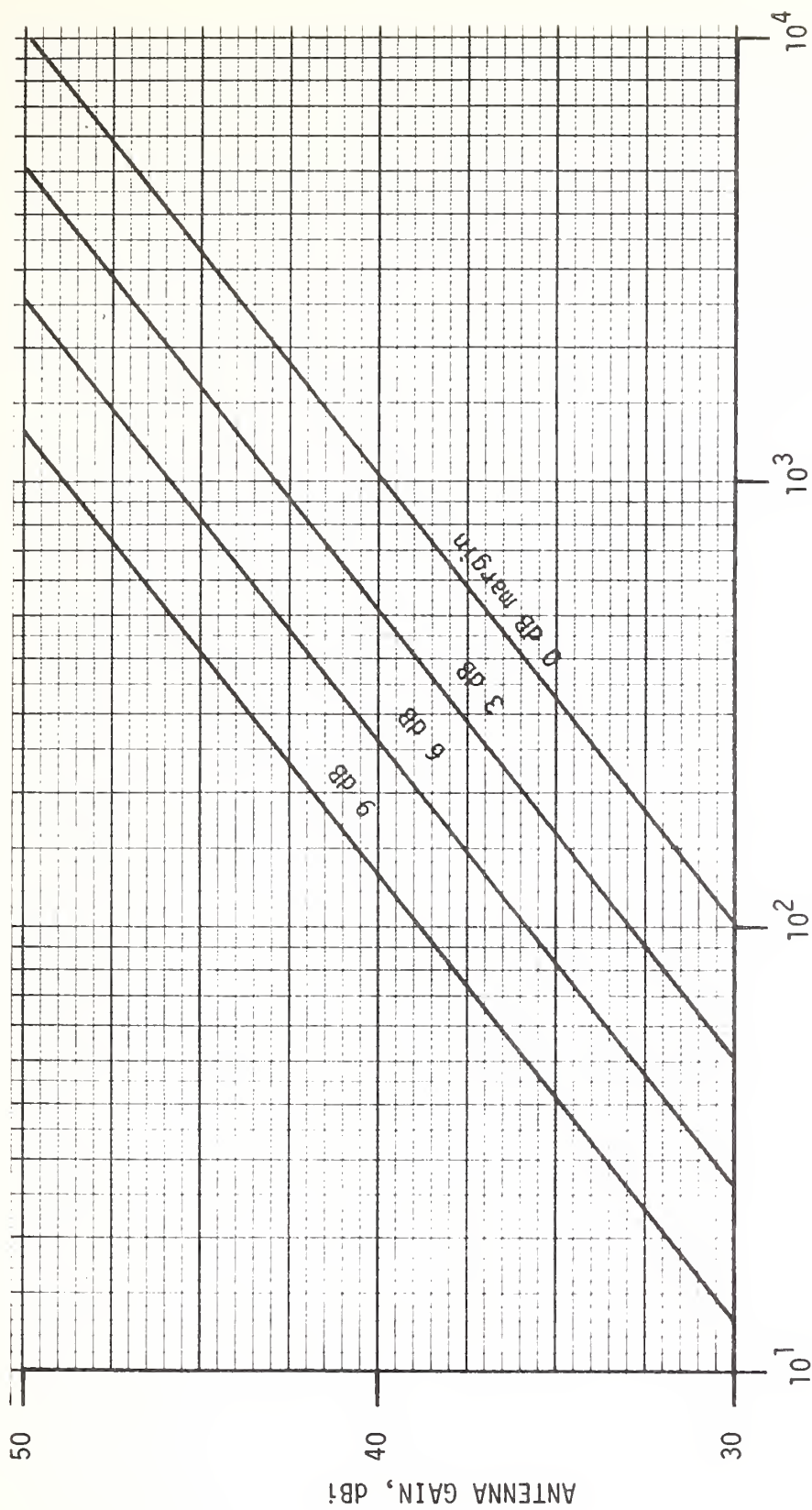


Figure A-2.5.--VHF APT, RCVR IF = 50 kHz  
40 degrees elevation





SYSTEM NOISE TEMPERATURE, DEGREES KELVIN

Figure A-3.1.--S-band, bit rate - 0.66 Mbps  
1 degree elevation

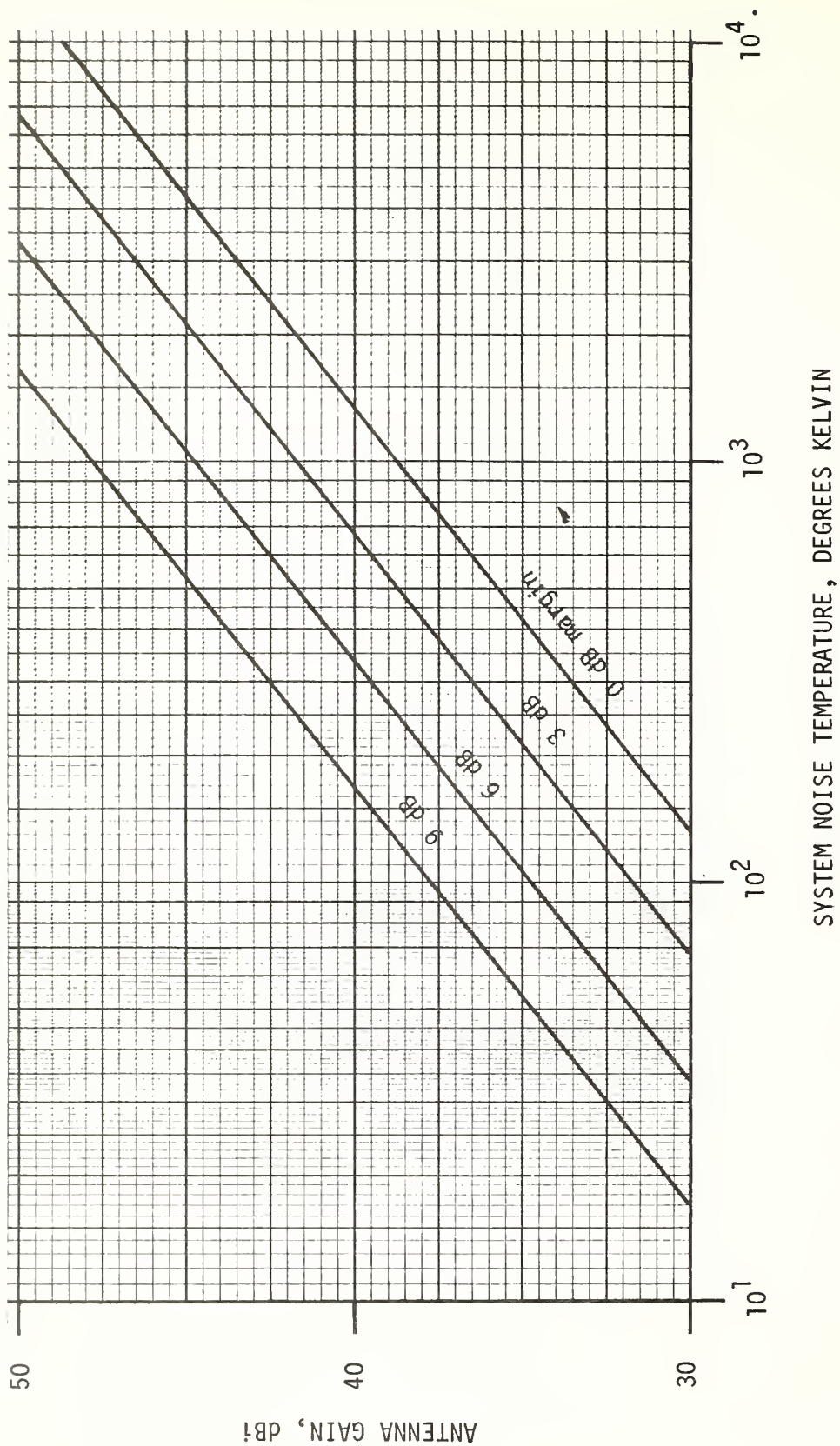
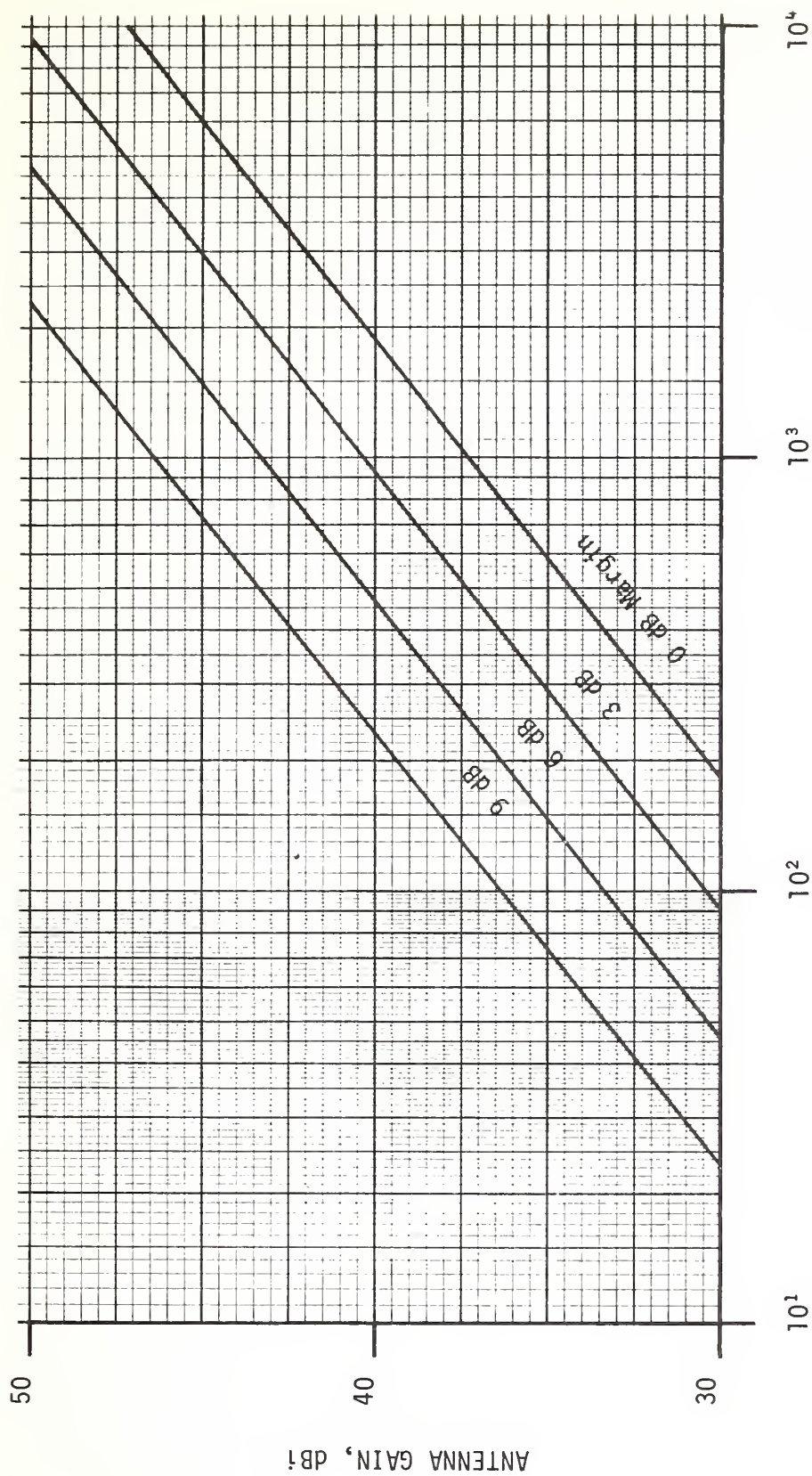
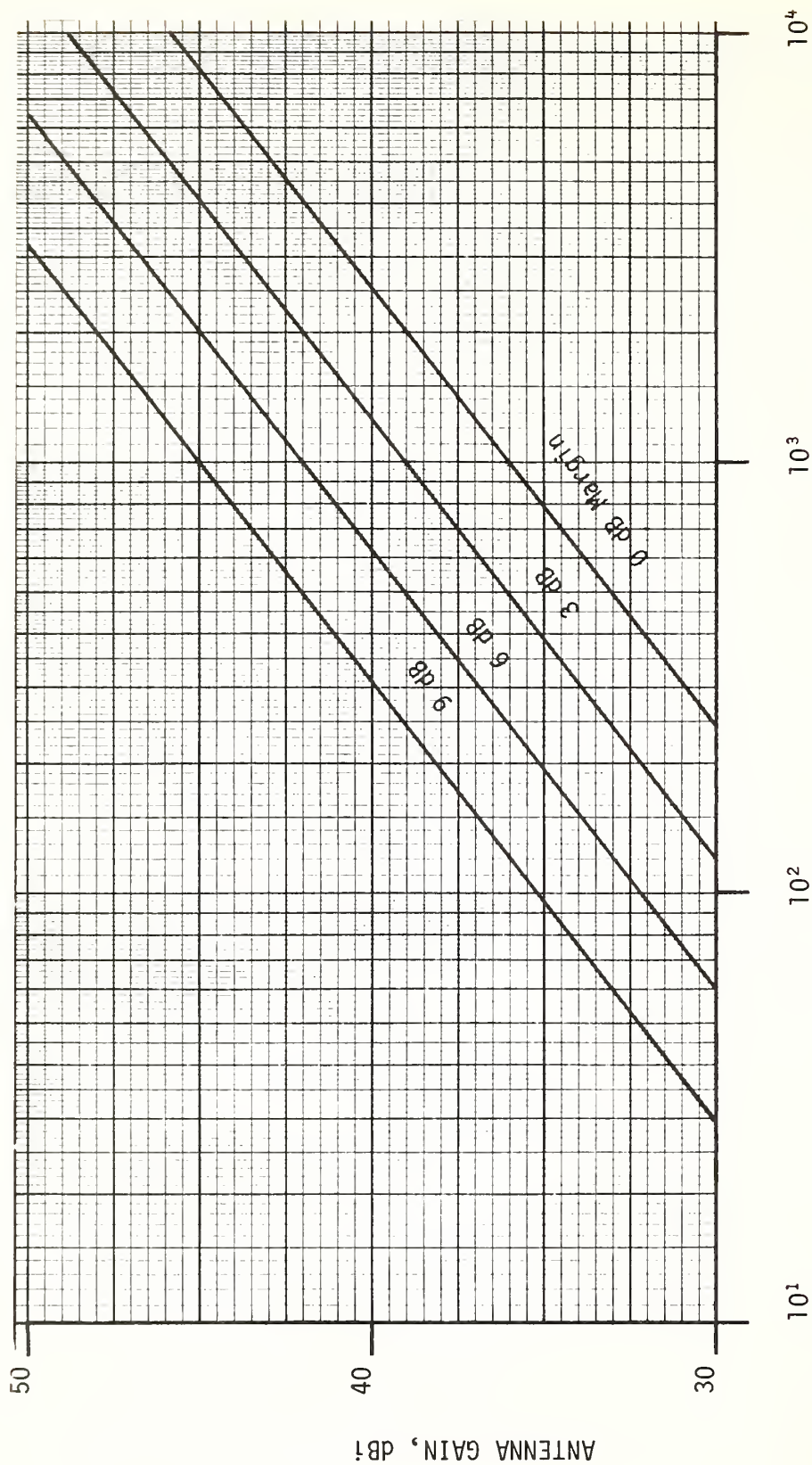


Figure A-3.2. --S-band, bit rate = 0.66 Mbps  
5 degree elevation



SYSTEM NOISE TEMPERATURE, DEGREES KELVIN

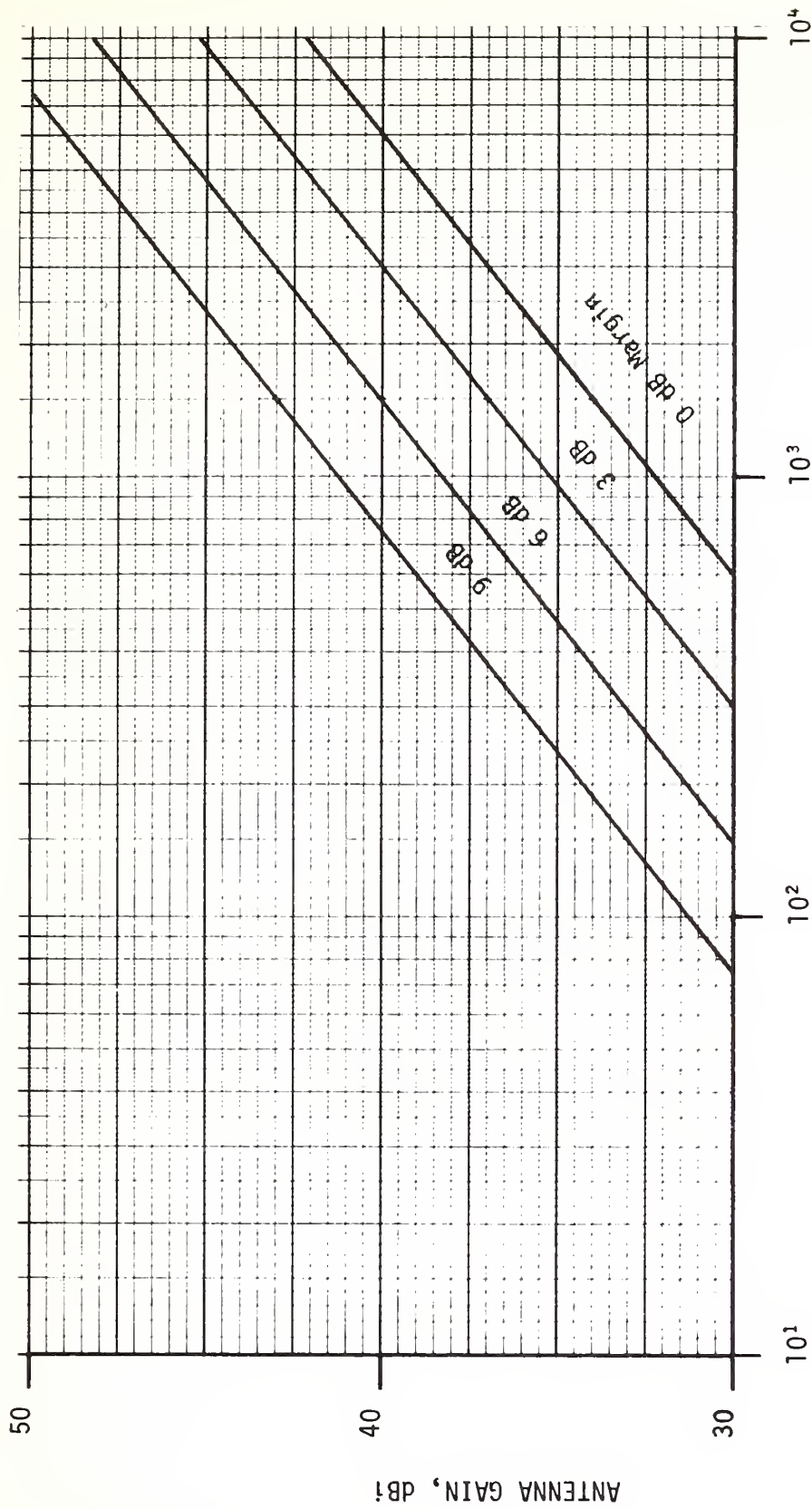
Figure A-3.3.-- S-band, bit rate = 0.66 Mbps  
10 degree elevation



SYSTEM NOISE TEMPERATURE, DEGREES KELVIN

Figure A-3.4.-- S-band, bit rate = 0.66 Mbps  
15 degree elevation





SYSTEM NOISE TEMPERATURE, DEGREES KELVIN

Figure A-3.5.-- S-band, bit rate = 0.66 Mbps  
40 degree elevation





## APPENDIX B - BASIC EQUATIONS

### B.1 Introduction

This appendix presents the basic orbital and electronic calculations for determining orbital parameters, Doppler shift and rate, and RF parameters. Results of derived equations are utilized in Sections 3 - 5.

### B.2 Orbital Mechanics

According to convention, a spacecraft becomes a satellite when it makes more than one revolution around the earth without the use of thrust to counteract the pull of gravity. Thus, for a satellite in a circular orbit, gravitational force counter-balances centrifugal force as shown by:

$$F_g = F_c$$

$$\frac{m_s GM}{r^2} = \frac{m_s v^2}{r}$$

So that:

$$v = (GM/r)^{\frac{1}{2}} \quad (B-1)$$

Where:

$F_g$  = the force due to gravity (newtons)

$F_c$  = the centrifugal force (newtons)

$m_s$  = the satellite mass (kg)

$r$  = the distance of the satellite from the center of the earth (m)

$v$  = the satellite velocity (m/sec)

$M$  = the mass of the earth

$G$  = the universal constant of gravitation

$$= 6.67 \times 10^{-11} \frac{m^3}{kg \cdot sec^2}$$

The satellite period  $T$  is the distance divided by the velocity; therefore:

$$T = \frac{2\pi r}{v} = 2\pi \left( \frac{r^3}{GM} \right)^{\frac{1}{2}} \quad (B-2)$$

### B.3 Range

The distance between the observer and the spacecraft may be readily calculated provided that the antenna elevation angle and the spacecraft altitude above the earth's surface are known. Referring to Figure B-1, the following parameters are defined:

- $r_e$  = earth's equatorial radius
- $s$  = height of the spacecraft above the earth
- $r$  = radius vector from the center of the earth to the spacecraft  
=  $r_e + s$
- $R$  = slant range
- $F$  = central angle
- $G$  =  $90^\circ +$  antenna elevation angle  $E$
- $E$  = antenna elevation angle
- $H$  =  $180^\circ - (F + G)$

The Law of Sines states that:

$$\frac{r_e}{\sin H} = \frac{r}{\sin G} = \frac{R}{\sin F} \quad (B-3)$$

$$\text{or} \\ \sin H = \frac{r_e \sin G}{r}$$

yielding the angle  $H$ . The central angle may now be calculated, since:

$$F = 180^\circ - (G + H)$$

or

$$F = 90^\circ - (E + H)$$

(B-4)

Knowing the value of the central angle, the height of the spacecraft, and the earth's radius, the range may now be calculated by the Law of Cosines yielding:

$$R = (r_e^2 + r^2 - 2rr_e \cos F)^{\frac{1}{2}} \quad (B-5)$$

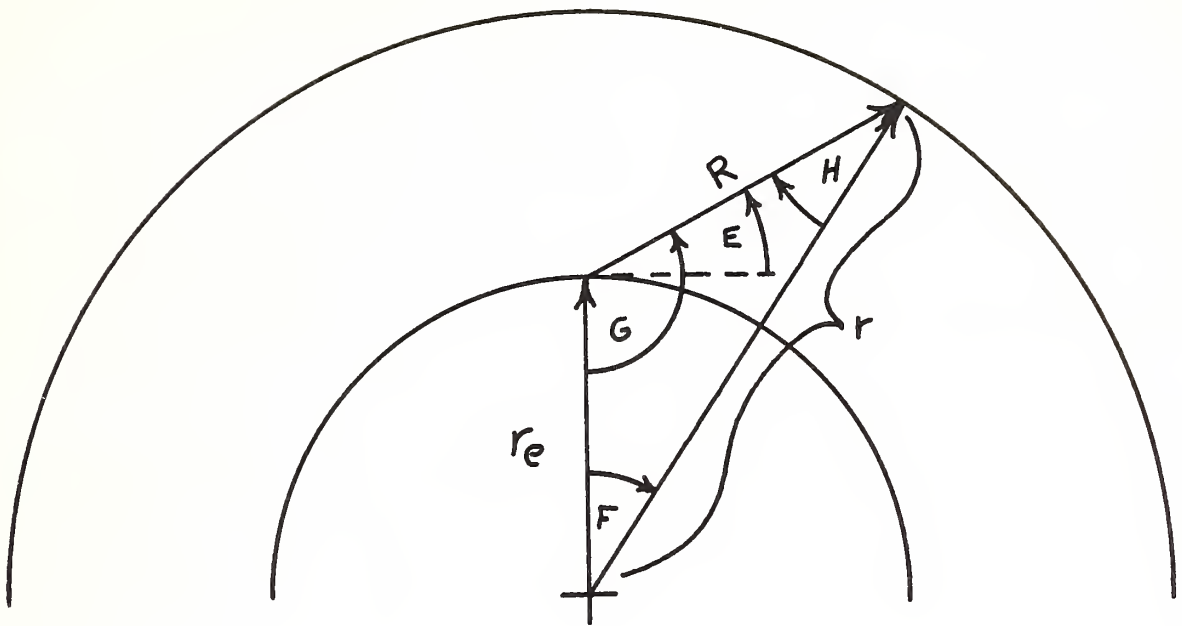


Figure B-1.--Orbit geometry

#### B.4 Range Rate

The range rate or the velocity that the range changes can be easily derived by differentiating the range equation (B-5) with respect to time.

$$\dot{R} = \frac{\dot{r}(r - r_e \cos F) + \dot{F} (rr_e \sin F)}{R} \quad (B-6)$$

Where:

$\dot{r}$  = rate of change of radius vector from the spacecraft to the center of the earth. For circular orbits  $r$  = constant and, therefore,  $\dot{r} = 0$ .

$\dot{F}$  = rate of change of the central angle and is found from the following equations:

$$\dot{F} = \frac{\text{orbital circumference}}{\text{orbital period}}$$

$$= \frac{2\pi r}{2\pi \left( \frac{r^3}{GM} \right)^{\frac{1}{2}}}$$

$$\dot{F} = \frac{(GM)^{\frac{1}{2}}}{r^{\frac{1}{2}}}$$

Putting the values in equation B-6 yields:

$$\dot{R} = \frac{(GM)^{\frac{1}{2}}(rr_e \sin F)}{R r^{\frac{1}{2}}} \quad (B-7)$$

#### B.5 Rate of Range Rate

The rate of range rate can also be easily derived by differentiating Equation B-7 with respect to time yielding, after simplifying:

$$\ddot{R} = \frac{GM r_e \cos F}{R r^2} - \frac{(\dot{R})^2}{R} \quad (B-8)$$



## B.6 Propagation Loss

If the power of a transmitter is denoted by  $P_t$  and if an omnidirectional antenna (isotropic) is used, the power density at a distance  $R$  from the transmitting antenna is equal to the transmitter power divided by the surface area  $4\pi R^2$  of an imaginary sphere of radius  $R$ . If the gain of the transmitting antenna ( $G_t$ ) is considered, then:

$$P_r = \frac{P_t G_t}{4\pi R^2} \quad (B-9)$$

Where  $P_r$  = received power.

Since the receive antenna captures a portion of the transmitted power and if the effective capture area of the receive antenna is  $A_r$ , then:

$$P_r = \frac{P_t G_t A_r}{4\pi R^2} \quad (B-10)$$

Antenna theory gives the relationship between antenna gain and effective area as:

$$G_t = \frac{4\pi A_t}{\lambda^2} \quad ; \quad G_r = \frac{4\pi A_r}{\lambda^2}$$

If isotropic antennas are to be used for both transmission and reception:

$$G_t = G_r = G = 1$$

and

$$A_t = A_r = A = \frac{\lambda^2}{4\pi}$$

Substituting into Equation B-10

$$P_r = \frac{P_t \lambda^2}{(4\pi R)^2} \quad (B-11)$$

Dividing by  $P_t$ , we obtain the ratio of received power to transmit power (propagation loss):

$$\frac{P_r}{P_t} = \frac{\lambda^2}{(4\pi R)^2} \quad (B-12)$$

For ease of calculations Equation B-12 is inverted giving the ratio of transmit to receive power. The space attenuation loss  $L = \frac{P_t}{P_r}$  in dB may be calculated using the following equation:

$$L(\text{dB}) = 10 \text{ Log } \frac{4\pi R^2}{\lambda^2} \quad (B-13)$$

where  $R$  and  $\lambda$  are in meters. Since:

$$\lambda = \frac{300}{F \text{ (MHz)}}$$

$$L(\text{dB}) = 10 \text{ Log } \frac{(4\pi)^2 \times 10^2}{9} + 20 \text{ Log } (RF) \quad (B-14)$$

where  $R$  is in KM and  $F$  is in MHz.

## B.7 Doppler Shift and Rate

Relative velocities of spacecraft to the ground observer are often great enough to produce shifts in frequency (Doppler shift) of significant magnitude. The Doppler shift corresponding to the range rate expression is:

$$D = \frac{\dot{R} (F)}{C - \dot{R}} \quad (B-15)$$

Where:

- $D$  = Doppler shift in Hz
- $C$  = speed of light =  $3 \times 10^8$  km/sec
- $\dot{R}$  = range rate in km/sec
- $F$  = center frequency in Hz

The rate of Doppler shift or Doppler rate is useful for purposes of determining required tracking rates and can be found by differentiating Equation B-15 with respect to time.

$$\dot{D} = \frac{C\ddot{R}}{(C-\dot{R})^2} \quad (F) \quad (B-16)$$

Where:

$\dot{D}$  = Doppler rate in Hz/sec  
 $\ddot{R}$  = rate of range rate in km/sec<sup>2</sup>

#### B.8 S/C RF Parameters

For TIROS-N all downlinks are a form of phase modulation. Therefore, the following discussion will apply only to phase modulation. In phase modulation, the instantaneous phase angle ( $\theta$ ) of the carrier is varied by the amplitude of the modulating signal. The expression for a carrier phase modulated by a single sinusoid is given by:

$$e(t) = E_C \sin (W_C t + \phi + \Delta\phi \cos W_m t) \quad (B-17)$$

Where:

$\Delta\phi$  = peak value of phase variation introduced by modulation and is defined as phase deviation  
 $W_m$  = modulation frequency, radians/sec

As seen from above, phase modulation looks very similar to frequency modulation, the difference being in the term  $\Delta\phi$ .  $\Delta\phi$  in  $F_m$  is replaced by  $\frac{\Delta F}{F_m}$  where  $\Delta F$  is the frequency and  $F_m$  is the modulating frequency. For phase modulation,  $\Delta\phi$  is a function of the amplitude of the modulating signal only. For a constant amplitude of modulating signal, the frequency band is directly proportional to the modulating frequency. The frequency band occupied by the side bands containing significant energy is given approximately by:

$$F = 2 F_m (1 + \Delta\phi) \quad (B-18)$$

where  $\Delta\phi$  is in radians.

### B-8.1 Carrier Power Versus Sideband Power

For TIROS-N, all downlinks contain square wave type of modulation. It is a well-known fact that the ratio of carrier power to total power for square wave modulation is:

$$\frac{P_c}{P_t} = \cos^2 \Delta\phi$$

or in dB

$$\left( \frac{P_c}{P_t} \right) \text{ dB} = 20 \log (\cos \Delta\phi) \quad (\text{B-19})$$

and the ratio of sideband power to total power is:

$$\frac{P_{SB}}{P_t} = \sin^2 \Delta\phi$$

or in dB

$$\left( \frac{P_{SB}}{P_t} \right) = 20 \log (\sin \Delta\phi) \quad (\text{B-20})$$

### B-8.2 Bandwidth

For square wave modulation, the power spectral density is of the form:

$$\left( \frac{\text{SIN } x}{x} \right)^2$$

Both NRZ and split phase signals are square wave encoded modulations where one bit equals the time interval  $T$  of the square wave. In NRZ codes, a one or zero bit causes a predefined level to occur in the square wave, whereas in split phase a one or zero causes a transition to occur in each bit. As a result, the instantaneous frequency of a NRZ stream can vary from zero to one-half the bit rate and, for a split phase stream, can vary from one half bit rate to bit rate. The power spectral density, therefore, is shown in Figure B-3 and B-4. For bandwidth consideration, most of the energy is contained up to the first zero crossing. Therefore, the effective  $F_m$  is BR for NRZ and 2BR for split phase where BR is bit rate. Plugging into Equation B-18 yields:

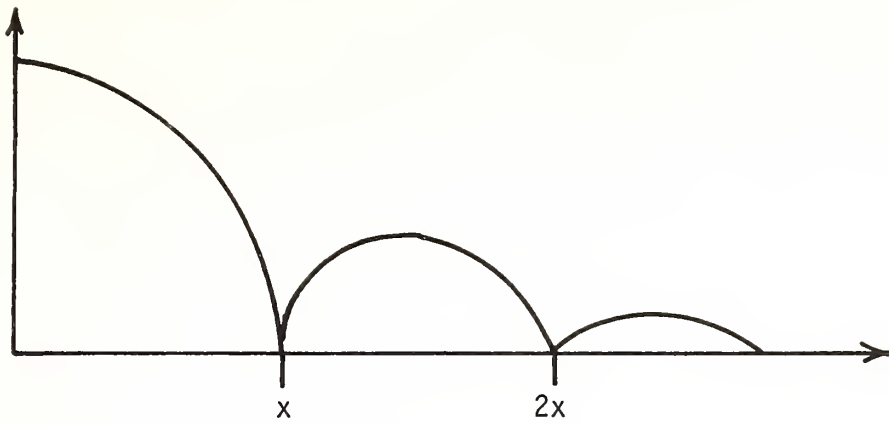


Figure B-2.-- $(\sin x/x)^2$  where  $x = 2\pi/T$

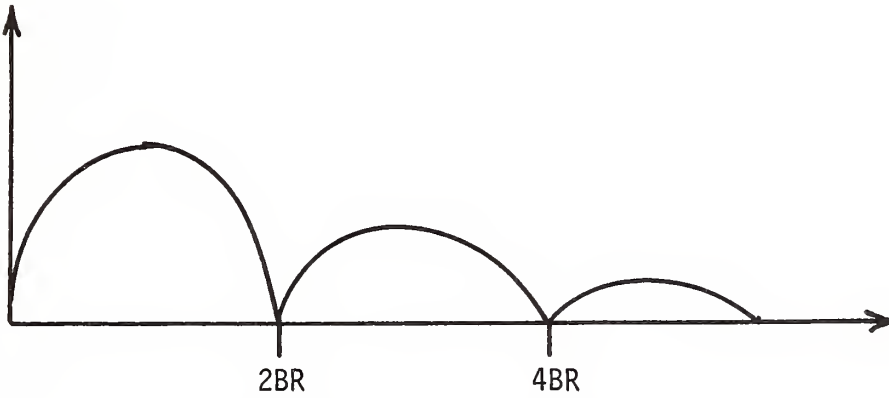


Figure B-3.--Split phase power density

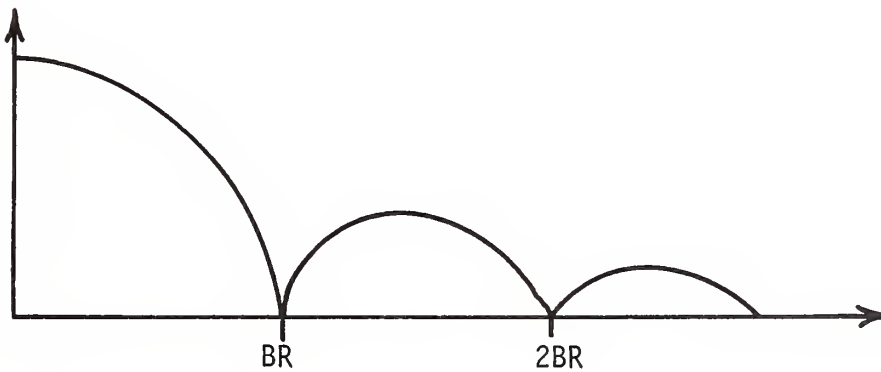


Figure B-4.--NRZ power density



$$F_{NRZ} = 2BR (1 + \Delta\phi) \quad (B-21)$$

and

$$F_{S\phi} = 4BR (1 + \Delta\phi) \quad (B-22)$$

#### B-9 Received Bandwidth

For purposes of determining receiver IF bandwidths required on the ground, several factors shall be considered. These are the instability of the S/C transmitter, RF transmitted bandwidth, and the Doppler shift. Total minimum received bandwidth is then:

$$BW_r = \underline{+F} \underline{+D} \underline{+S} \quad (B-23)$$

Where:

F =  $\frac{1}{2}$  RF bandwidth

D = Doppler shift

S = transmitter instability and offset from center frequency

## APPENDIX C - ANTENNA MOVEMENTS

### C.1 Introduction

The purpose of this appendix is to briefly describe and discuss ground antenna mounts and drive systems. Three basic antenna systems will be talked about: 1) Az-El mount with 90-degree maximum elevation, 2) Az-El mount with capability of 180-degree rotation in elevation axis, and 3) X-Y mount. Category 1 above will be discussed in the most detail since it is the most common antenna mount and is the cheapest and lightest to construct. Required velocities for each axis will be presented along with the data loss in seconds for category 1 above. It is the intention of this section to only present information and not to design the mounts. Other designers might find a better approach to the problems of antenna mounts and drive systems than that presented here.

### C.2 Az-El Mount with 90-Degree Limitation

The Az-El mount is an inexpensive, lightweight, and easy mount to construct. The antenna consists of two axes: 1) Azimuth (Az) and 2) Elevation (El). The azimuth axis usually rotates through an angle greater than 360 degrees around a plane parallel to the earth's surface. The elevation axis, in this case, rotates to an angle of only 90 degrees in the vertical plane (plane perpendicular to azimuth plane). Normally for ease of construction, the elevation axis is placed above the azimuth axis giving rise to the name "elevation over azimuth antenna." The reference point for locating both axes is that the true north horizon corresponds to 0 degrees in azimuth and elevation. Eastern horizon would then be 90 degrees azimuth and 0 degrees elevation, and so forth. Plus 90 degrees elevation occurs at zenith and, at zenith, the azimuth angle can be any degree.

An awkward situation occurs on Az-El antennas of this type which makes tracking a satellite in earth orbit difficult. When satellites approach zenith where the limit on elevation angle is neared, then the antenna must rotate many degrees in the azimuth axis (sometimes as much as 180 degrees) in order to "catch" the satellite as it begins the back side of the pass (going from zenith back to the horizon). As the antenna rotates in azimuth through this situation, the elevation angle is generally held constant. If the azimuth rate is too slow then the antenna will have arrived at the intercept point too late and manual intervention would be required to catch up to the spacecraft. On the other hand, if the rate is too fast, then the antenna will arrive early and must be stopped until the satellite arrives. So far, only the antenna movement was discussed. A secondary problem will be related to the RF beamwidth of the antenna. If the beamwidth is wide enough, no loss of data would occur as the antenna rotates in azimuth. However, if the beamwidth is too narrow then loss of data could occur even though the antenna and spacecraft arrive at the intercept point simultaneously. More will be said about this in the appropriate paragraphs.

The highest elevation angle the antenna can possibly achieve will be defined in this document as the "cone of silence" and is referenced from zenith.

The initial parameters needed for any antenna drive are the maximum velocity and maximum acceleration that the antenna must move to keep track of a spacecraft. In order to determine these parameters, a worst case situation must be used and then applied to each axis of the driving antenna. The worst case situation for satellite to ground tracking for satellites in earth orbit occurs when a spacecraft starts at the horizon and rises directly overhead for a maximum angle of 90 degrees in the antenna axis plane. This "directly overhead pass" may occur rarely or very frequently depending upon spacecraft altitude and inclination and upon the ground station latitude and longitude. In any case, one can be assured that it will occur at some time.

The rates of antenna motion will vary as the spacecraft rises from horizon to directly overhead. At the horizon, the spacecraft appears to move very slowly, hence a slow rate on the ground antenna is required. However, at zenith, the spacecraft appears to have speeded up and will be moving very rapidly relative to the stationary ground observer, thus necessitating a faster moving ground antenna. The two parameters to describe this motion are velocity and acceleration.

#### C-2.1 Elevation Rates

The elevation, velocity, and acceleration of the elevation axis for an overhead pass can be found using Figure B-1 and the Law of Cosines.

$$r^2 = R^2 + r_e^2 - 2R r_e \cos G \quad (C-1)$$

Rewriting Equation C-1:

$$\cos G = \frac{R^2 + r_e^2 - r^2}{2R r_e} \quad (C-2)$$

The elevation angle can be found from Equation C-2 or by using the relationship:

$$G = 90 + E \quad (C-3)$$

By differentiating Equations C-2 and C-3 with respect to time and simplifying the result yields:

$$\dot{G} = \dot{E}$$

and

$$\dot{G} = \dot{R} \frac{(r_e \cos G - R)}{r_e R \sin G} \quad (C-4)$$

Where:

$\dot{G}$  = angular velocity of elevation axis in radians/sec

$\dot{R}$  = range rate

Again, differentiating Equation C-4 with respect to time and simplifying results yields:

$$\ddot{G} = \ddot{E}$$

and

(C-5)

$$\ddot{G} = \left[ \ddot{R} - \frac{(\dot{R})^2}{R} - \frac{\dot{R}\dot{G}}{\tan G} \right] \left[ \frac{1}{R \tan G} - \frac{1}{r_e \sin G} \right] - \frac{\dot{R}}{R} \left[ \dot{G} + \frac{\dot{R}}{r_e \sin G} \right]$$

Where:

$\ddot{G}$  = angular acceleration of elevation axis in radians/sec<sup>2</sup>

$\ddot{R}$  = rate of range rate

By picking an elevation E, the velocity and acceleration can be determined.

Equations C-4 and C-5 are plotted as a function of E in Figures C-1 and C-2, respectively. As shown, the maximum velocity occurs around 90 degrees and is 0.51 degrees per second. The maximum acceleration occurs around 58 degrees and is 0.00265 degrees per second<sup>2</sup>.

## C-2.2 Azimuth Rates

The next step is to determine the azimuth rate required. This is difficult to determine because of the cone of silence which occurs around zenith for this antenna type. One solution to this problem is to make some assumptions concerning the antenna and orbital track and then calculate the rate. For this document, the information supplied should satisfy the worst case situation conceivable. The assumptions made are the following:



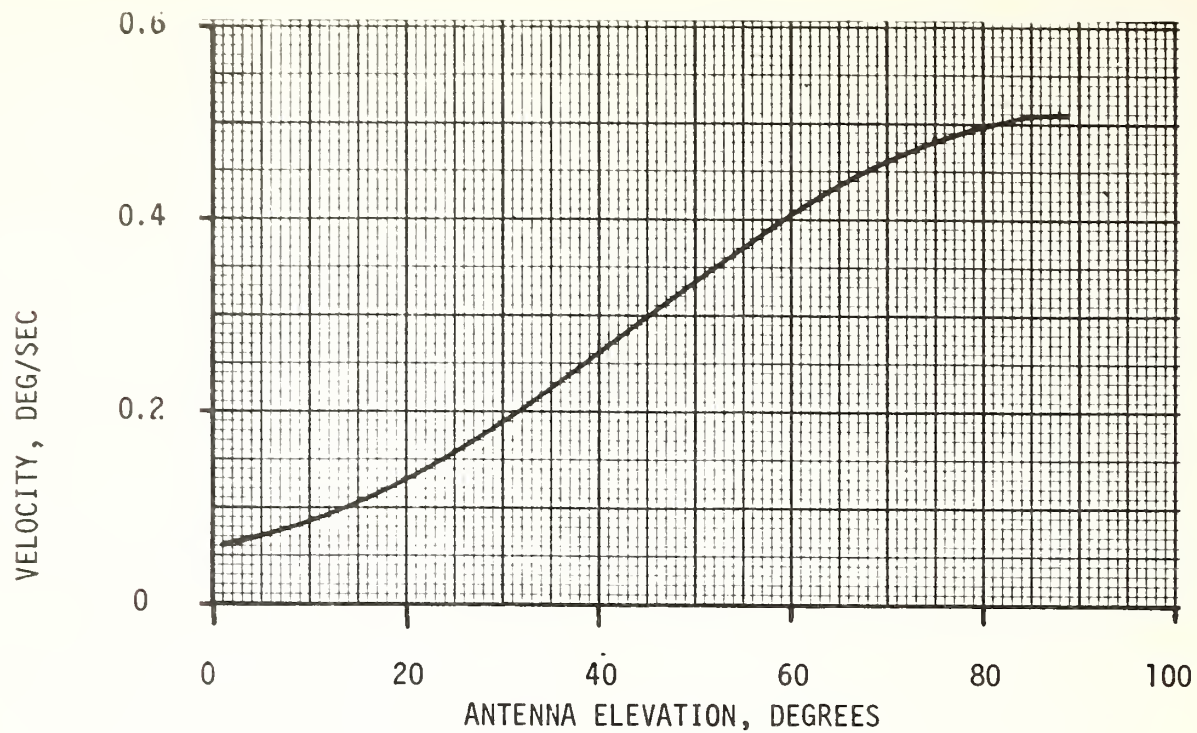


Figure C-1.--S/C-antenna elevation axis rate

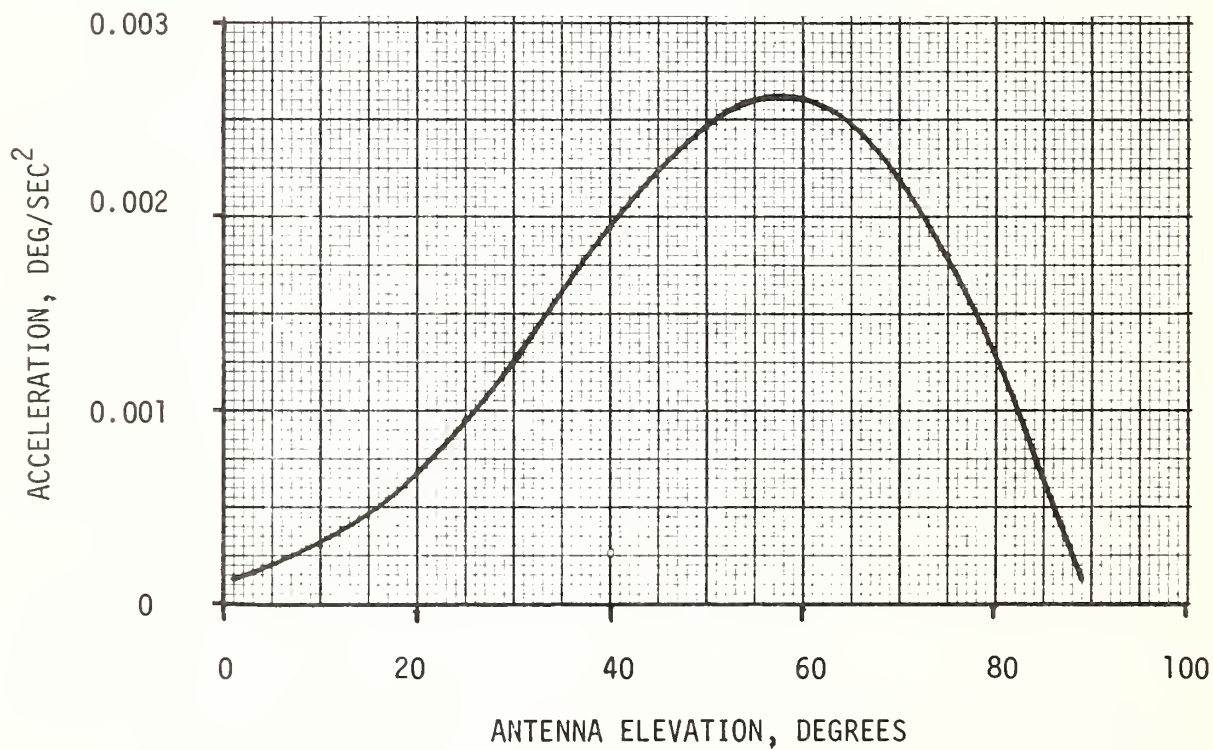


Figure C-2.--S/C-antenna elevation axis acceleration



1) The worst case pass will be used; i.e., the spacecraft starts at the horizon and passes directly overhead for a maximum elevation angle of 90 degrees.

2) The antenna will track in elevation only up to the cone of silence. Therefore, should the cone of silence be 2 degrees, then the elevation axis can only be moved electrically/automatically to 88 degrees.

3) The azimuth axis must rotate, for a directly overhead pass, through a maximum of 180 degrees while holding the elevation angle constant.

4) The antenna follows the spacecraft up to the cone of silence and then begins its rotation about the azimuth axis. Upon completion of rotation, the antenna and spacecraft arrive at the intercept point (on the back side of the pass) simultaneously and normal tracking is resumed.

Generally, the above assumptions are more tightly specified than will be found in common practice. However, the reader can be assured that if the antenna meets these assumptions, then the antenna will operate correctly for any situation.

From Appendix B and Figure B-1, the satellite orbital period is:

$$T = 2\pi \sqrt{\frac{R^3}{GM}}$$

Since the central angle  $F$  must rotate  $2\pi$  radians in one orbital period, the central angle velocity is:

$$\dot{F} = \frac{2\pi}{T} = \sqrt{\frac{GM}{R^3}} \text{ rad/sec}$$

The next step is to find the central angle by picking the elevation angle  $E$  using:

$$F = 90 - (E + h)$$

and

$$\sin h = \frac{r_e \cos E}{R}$$

Therefore, the time it takes the spacecraft to go from the elevation angle  $E$  to 90 degrees is:

$$t = \frac{F}{\dot{F}}$$

For the azimuth slew, the spacecraft travels the angle  $-F$  to  $+F$  for a total time of  $2t$ . During this  $2t$  time, the azimuth axis must rotate 180 degrees, worst case, resulting in the velocity defined by:

$$V_{AZ} = \frac{180}{2t} = \frac{90}{t} \text{ degrees/sec}$$

The azimuth velocity versus the antenna elevation/cone of silence is shown in Figure C-3. As shown, below about 88 degrees elevation, the required azimuth velocity slowly increases while above 88 degrees, the required velocity increases rapidly. Generally, cone of silence of 2 degrees is typical. From the figure, an azimuth velocity of about 23 degrees per second is needed to support the 2 degree cone of silence. The designer should decide upon the maximum elevation angle/cone of silence he wishes to support and then read off the required azimuth rate from the figure.

### C-2.3 Data Loss

The prior discussion has applied only to the mechanical motion of this type of antenna. Further consideration must be given to the effect of the RF beamwidth on the tracking ability. Under many conditions of beamwidth, the antenna will track the satellite smoothly with no loss of data. However, other conditions exist when the RF beam is very narrow where the antenna tracks the satellite, but the telemetered data will be outside the antenna beamwidth resulting in a data loss. This section will attempt to provide enough information to the designer so that he may have an indication of the data loss amount of his antenna.

Each antenna has a parameter known as the RF beamwidth and is normally specified at the  $-3$  dB points. This RF beamwidth parameter defines the directivity of the antenna and will vary according to the frequency and size of the antenna. As an example, an 85-foot parabolic antenna may have a  $-3$  dB beamwidth of around 0.5 degrees at S-band while at VHF it is around 6 degrees. As long as the satellite transmitted power is received within the ground antenna beamwidth, the data can be received and the antenna can automatically follow the satellite motion. This assumes, of course, that the received power is above the threshold of the system. For this section, the RF beamwidth is assumed to be specified at the  $-3$  dB points and that there is sufficient margin (above 3 dB) in the tracking system link. The calculations and figures presented here could also be used for beamwidths specified to be  $-1$  dB. In other words, the specification can be anything as long as the designer is careful in using the results. He must be sure that he has enough signal level in his tracking system.

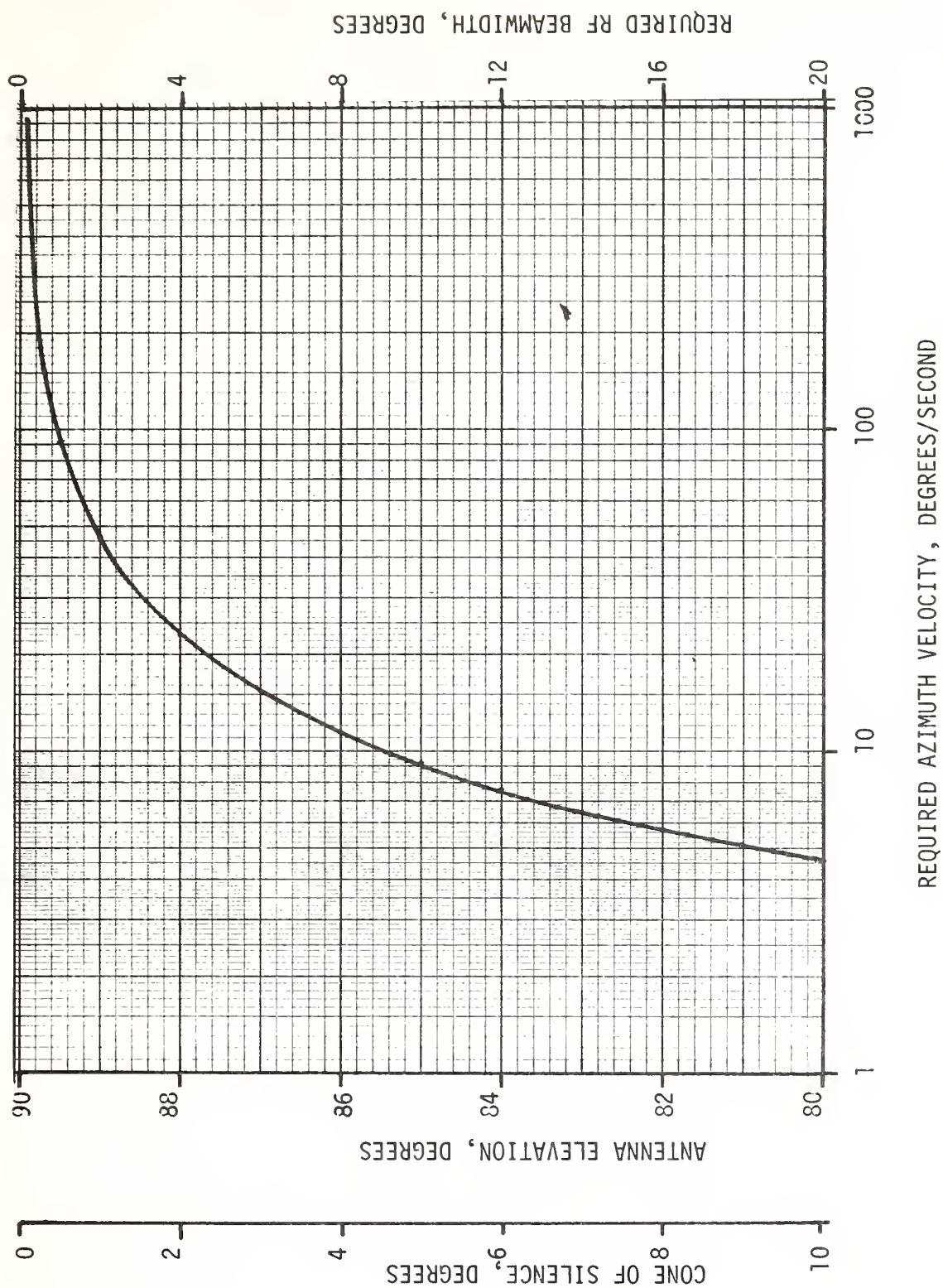


Figure C-3.--Required RF beamwidth and azimuth velocity as a function of elevation and cone of silence for an overhead pass and no data loss on an AZ-EL mount

The term data loss is specified in units of seconds and can be defined as the total time where the satellite signal falls outside the ground antenna beamwidth while the antenna is attempting to follow the satellite. Figure C-4 defines the geometry for data loss. As shown, the RF beamwidth is centered around the angle  $G$  ( $90 + E$ ) which also defines the cone of silence. No data loss exists as long as  $G + \frac{1}{2}RF \geq 180$ . In the following calculations, a prime placed with the value refers to the effective value in order that Figure B-1 can also be used. Therefore:

$C$  = cone of silence  
 $RF$  = RF beamwidth  
 $G' = 90 + E'$   
 $E' = 90 - C + \frac{1}{2}RF$

$$\sin h' = \frac{r_e \sin G'}{R}$$

$$F' = 90 - (E' + h')$$

and the data loss time is defined by:

$$t = \frac{2F'}{\dot{F}}$$

where:  $\dot{F}$  = central angle velocity (from Section C-2.2).

The data loss results are shown in Figures C-3 and C-5. Figure C-3 shows the required RF beamwidth versus the cone of silence assuming the required azimuth velocity has been chosen and no data loss. For example, a cone of silence of 2 degrees (maximum elevation of 88 degrees) requires an azimuth velocity of 23 degrees per second and a RF beamwidth of at least 4 degrees in order to not lose any data. Figure C-5, on the other hand, presents the case whereby data loss is incurred when the beamwidth is too narrow. As an example, a data loss of 4 seconds is incurred when a cone of silence of 1.5 degrees and a RF beamwidth of 1 degree are used. For both figures, the worst case satellite pass occurs and it is assumed that the required azimuth rate is used.

### C-3 Az-El Mount with Capability of 180 Degree Rotation in Elevation Axis

The 90 degree elevation limited Az-El antenna can be modified for space applications in order to prevent data losses at zenith. This modification allows the elevation axis to rotate 180 degrees instead of only 90 degrees. The actual mechanical modification is normally easy to accomplish on the mount; however, a much more complex servo drive system would be required. This modification causes this type of antenna to be slightly more expensive

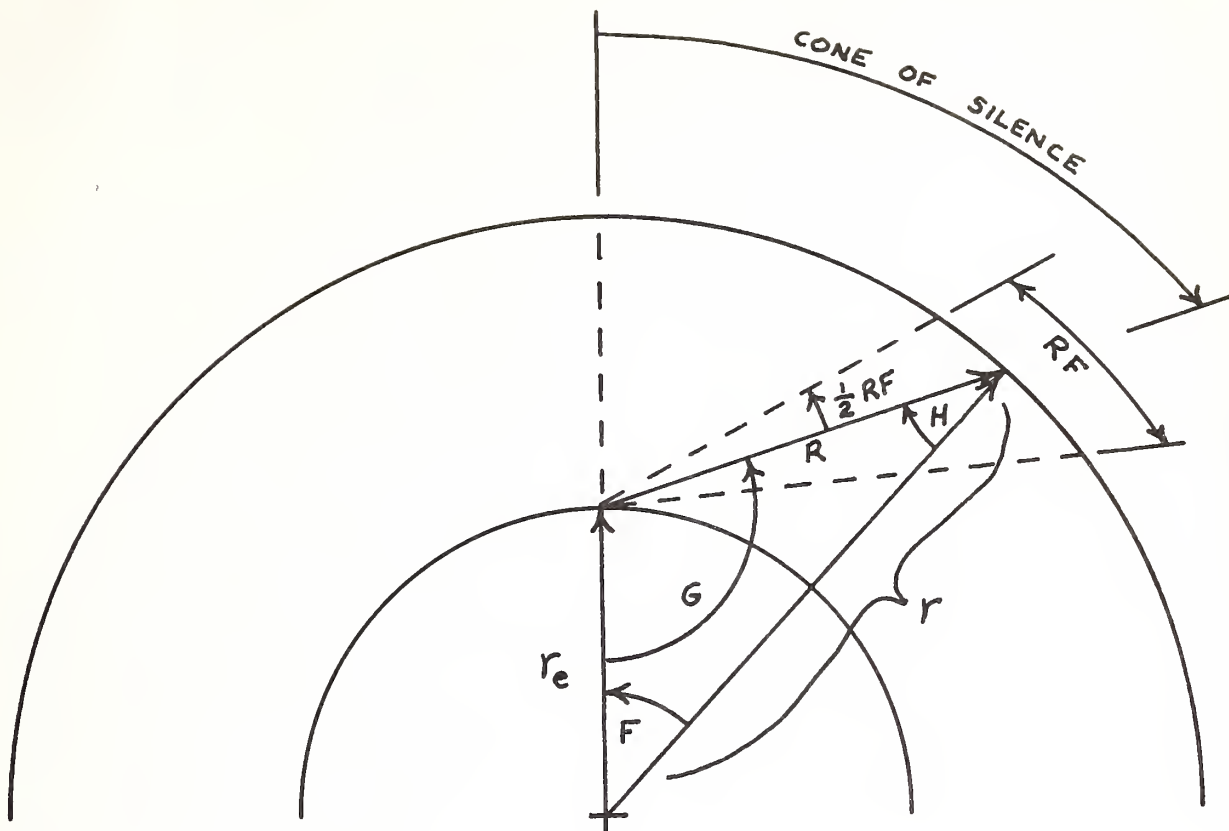


Figure C-4.--RF beamwidth geometry



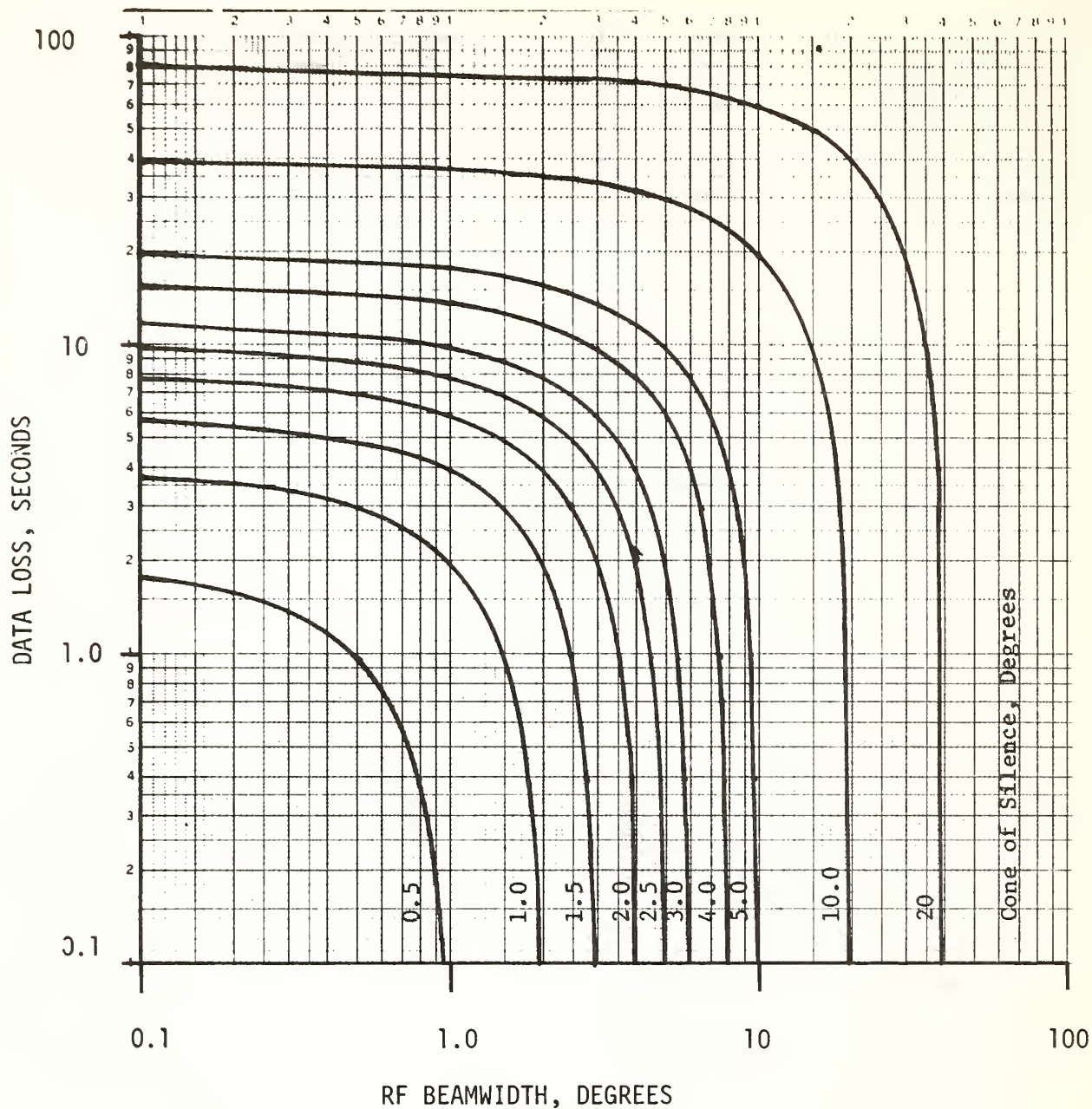


Figure C-5.--Data loss as a function of RF beamwidth and cone of silence for an overhead pass, assuming that the AZ velocity is such that the S/C and antenna meet together at the end of the azimuth rotation

than the previously talked about antenna. The advantage of this antenna is that it tracks the satellite through zenith without a drastic azimuth rotation. In fact., this antenna approximates the more complicated and expensive X-Y mounts. This antenna, however, has not been put into general usage probably because of the increased servo system complexity. The angle references are normally the same as the 90 degree limited antenna with the exception that 180 degree elevation, 180 azimuth corresponds to the southern horizon.

For this antenna, the elevation axis rates are the same as shown in Figures C-1 and C-2 and discussed in paragraph C-2.1. The azimuth rates have not been calculated and are left up to the designer should he use this type antenna.

#### C-4 X-Y Mount

The X-Y mount is more expensive, heavier, and harder to construct than the prior antennas mentioned. This antenna consists of two axes: 1) the X axis and 2) the Y axis. Both axes rotate through a total angle of 180 degrees from horizon to horizon with the X axis aligned in the west-east plane and the Y axis aligned in the north-south plane. The reference point for locating both axes is that directly overhead (zenith, true vertical from the ground) corresponds to 0 degrees in both axes. The angle reference range is then from -90 to +90 degrees with +90 degrees referenced to north in the Y axis and east in the X axis.

As can be envisioned, this antenna is ideal for earth-orbiting space applications since it can "fold over" in both directions through an overhead pass. This antenna, however, does have a similar awkward situation as the Az-EI mount and occurs at the horizon in each axis plane. Thus, the antenna cannot track a satellite at the horizon at the north, east, south, or west positions. Normal X-Y mounts have been able to restrict the non-tracking range to a maximum of 5 degrees elevation off the horizon. Considering that below 5 degrees elevation, the satellite signal is very weak and the station observer is trying to acquire; it appears that the antenna tracking problem for this mount is insignificant. Thus, very little or no data loss will be observed for this mount. The disadvantages of this antenna, as mentioned before, are the cost, weight, and complexity. As a result, these antennas are not widely used by the general user.

Since both axes "fold over," the rates for each axis are easily calculated. The rates shown in Figures C-1 and C-2 apply to this antenna for both the X and Y axis.

## APPENDIX D - REFERENCES

1. TIROS-N System Definition Study Report, Submission 2, Volume II, January 1975, prepared for NASA/GSFC under Contract No. NAS5-20644.
2. TIROS-N Support Instrumentation Requirements Document (SIRD), NASA, March, 1975.
3. TIROS-N/NOAA Spacecraft System Baseline Description (Preliminary), SSTD-4, T.J. Karras and P.H. Eyclesheimer, February 1975, TIROS-N Ground System Project, NESS/NOAA/DOC.
4. Flight Performance Handbook for Orbital Operations, Raymond W. Wolverton, 1963, John Wiley and Sons, Inc.
5. Vector Mechanics for Engineers, Statics and Dynamics, Ferdinand P. Beer and E. Russell Johnston, Jr., 1962, McGraw-Hill Book Company, Inc.
6. Calculations of Signal-to-Noise Margins for STADAN - Spacecraft Links, X-531-69-XX, Preliminary, April 1969, Goddard Space Flight Center.
7. Antenna and Receiving System Noise Temperature Calculation, L.V. Blake, September 1961, U.S. Naval Research Laboratory.
8. Principles of Communication Systems, Herbert Taub and Donald L. Schilling, 1971, McGraw-Hill Book Company, Inc.
9. Reference Data for Radio Engineers, Fifth Edition, March 1969, Howard W. Sams and Co., Inc.
10. Communications Electronics Circuits, J.J. DeFrance, December 1966, Holt, Rinehart and Winston, Inc.
11. Information Transmission, Modulation, and Noise, Mischa Schwartz, 1959, McGraw-Hill Book Company, Inc.
12. The NOAA Operational Environmental Satellite System - Status and Plans, Dr. George H. Ludwig, January 1975, U.S. Department of Commerce/NOAA/NESS, Washington, D.C.
13. The Future Polar Orbiting Environmental Satellite System, Dr. George H. Ludwig, 1974, NOAA/NESS, Washington, D.C.
14. Interface Specification, TIROS-N Satellite- Ground System, IS-2285557, Rev. B, RCA Corporation.
15. Memorandum from Robert M. White, U.S. Representative to the WMO, to the Secretary General, World Meteorological Organization, March 1976, entitled, "TIROS-N Real-Time Data Systems."

## APPENDIX E - ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ADACS	Attitude Determination and Control Subsystem
AM	Amplitude Modulation
Ant	Antenna
APT	Automatic Picture Transmission
AVHRR	Advanced Very High Resolution Radiometer
Az	Azimuth
BER	Bit Error Rate
bps, BPS	bits per second
BR	Bit Rate
BSU	Basic Sounding Unit
BW	Bandwidth
°C	Centigrade degrees
CDA	Command and Data Acquisition
CIU	Controls Interface Unit
CM	Centimeter
C/N	Carrier-to-Noise
$\Delta\phi$	Phase Modulation Index
dB	Decibels
dB <sub>i</sub>	Decibels referenced to isotropic
dB <sub>m</sub>	Decibels referenced to 1 milliwatt
DC	Direct Current
DCP	Data Collection Platform
DCPLS	Data Collection and Platform Location System

DCS	Data Collection System
deg	Degree
Demod	Demodulator
DOC	Department of Commerce
DPU	Data Processing Unit
DSB	Double Sideband
$E_b/N_0$	Energy per bit/Noise bandwidth
EIRP	Effective Isotropic Radiated Power
E1	Elevation
etc.	and so forth
FGGE	First GARP Global Experiment
Fm	Modulating Frequency
FM	Frequency Modulation
FSK	Frequency Shift Keyed
G	Gain
GAC	Global Area Coverage
GARP	Global Atmospheric Research Program
GHz	giga-Hertz
Gnd	Ground
HEPAT	High Energy Proton Alpha Telescope
HRPT	High Resolution Picture Transmission
Hz	Hertz
i.e.,	that is
IF	Intermediate Frequency
IFOV	Instantaneous Field of View
IR	Infrared



ITOS	Improved TIROS Operational Satellite
OK	Kelvin degrees
kbps	kilo bits per second
kev	kilo electron volts
kg, Kg	Kilogram
kHz, KHz	kiloHertz
km, KM	kilometer
LAC	Limited Area Coverage
LCP	Left Circularly Polarized
LEPAT	Low Energy Proton Alpha Telescope
m	Meter
Max	Maximum
Mb	millibars
Mbps	Mega bits per second
mev	million electron volts
MHz	MegaHertz
Min	Minimum
MIRP	Manipulated Information Rate Processor
mm	millimeter
Mod	Modulation
ms	millisecond
MSU	Microwave Sounding Unit
MTR	Motor
mw	milliwatt
NASA	National Aeronautics and Space Administration
NESS	National Environmental Satellite Service

Net.	Network
n. mi.	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
NRZ	Non Return to Zero
NSD	Noise Spectral Density
osc	Oscillator
paramp	Parametric Amplifier
PCM	Pulse Code Modulation
PM <sub>c</sub>	Phase Modulation
POD	Proton Omnidirectional Detector
preamp	Preamplifier
PSK	Phase Shift Keyed
R	Tracking Rate
RCP	Right Circularly Polarized
Rcv'd	Received
RCVR	Receiver
Rec, REC	Recorder, Record
Req'd	Required
RF	Radio Frequency
rms	root mean square
S/C	spacecraft
sec	seconds
SEM	Space Environment Monitoring
S/N	Signal to Noise
S $\phi$	Split Phase
SR	Scanning Radiometer

SSU	Stratospheric Sounding Unit
sync	Synchronization
sys	System
T	Temperature
TED	Total Energy Detectors
TIROS	Television Infrared Observation Satellite
TIP	TIROS Information Processor
TOVS	TIROS Operational Vertical Sounder
T/R	Tape Recorder
TX, XMTR, TRANS	Transmitter
UHF	Ultra High Frequency
$\mu\text{m}$	micrometer
v	Volts
VCO	Voltage Controlled Oscillator
vdc	Volts, direct current
VHF	Very High Frequency
VHRR	Very High Resolution Radiometer
VS, vs.	versus
W	Watts
XTAL	Crystal



(Continued from inside front cover)

- NESC 56 Time-Longitude Sections of Tropical Cloudiness (December 1966-November 1967). J. M. Wallace, July 1970, 37 pp. (COM-71-00131)

NOAA Technical Reports

- NESS 55 The Use of Satellite-Observed Cloud Patterns in Northern Hemisphere 500-mb Numerical Analysis. Roland E. Nagle and Christopher M. Hayden, April 1971, 25 pp. plus appendixes A, B, and C. (COM-73-50262)
- NESS 57 Table of Scattering Function of Infrared Radiation for Water Clouds. Giichi Yamamoto, Masayuki Tanaka, and Shoji Asano, April 1971, 8 pp. plus tables. (COM-71-50312)
- NESS 58 The Airborne ITPR Brassboard Experiment. W. L. Smith, D. T. Hilleary, E. C. Baldwin, W. Jacob, H. Jacobowitz, G. Nelson, S. Soules, and D. Q. Wark, March 1972, 74 pp. (COM-72-10557)
- NESS 59 Temperature Sounding From Satellites. S. Fritz, D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, July 1972, 49 pp. (COM-72-50963)
- NESS 60 Satellite Measurements of Aerosol Backscattered Radiation From the Nimbus F Earth Radiation Budget Experiment. H. Jacobowitz, W. L. Smith, and A. J. Drummond, August 1972, 9 pp. (COM-72-51031)
- NESS 61 The Measurement of Atmospheric Transmittance From Sun and Sky With an Infrared Vertical Sounder. W. L. Smith and H. B. Howell, September 1972, 16 pp. (COM-73-50020)
- NESS 62 Proposed Calibration Target for the Visible Channel of a Satellite Radiometer. K. L. Coulson and H. Jacobowitz, October 1972, 27 pp. (COM-73-10143)
- NESS 63 Verification of Operational SIRS B Temperature Retrievals. Harold J. Brodrick and Christopher M. Hayden, December 1972, 26 pp. (COM-73-50279)
- NESS 64 Radiometric Techniques for Observing the Atmosphere From Aircraft. William L. Smith and Warren J. Jacob, January 1973, 12 pp. (COM-73-50376)
- NESS 65 Satellite Infrared Soundings From NOAA Spacecraft. L. M. McMillin, D. Q. Wark, J. M. Siomkajlo, P. G. Abel, A. Werbowetzki, L. A. Lauritson, J. A. Pritchard, D. S. Crosby, H. M. Woolf, R. C. Luebbe, M. P. Weinreb, H. E. Fleming, F. E. Bittner, and C. M. Hayden, September 1973, 112 pp. (COM-73-50936/6AS)
- NESS 66 Effects of Aerosols on the Determination of the Temperature of the Earth's Surface From Radiance Measurements at 11.2  $\mu$ m. H. Jacobowitz and K. L. Coulson, September 1973, 18 pp. (COM-74-50013)
- NESS 67 Vertical Resolution of Temperature Profiles for High Resolution Infrared Radiation Sounder (HIRS). Y. M. Chen, H. M. Woolf, and W. L. Smith, January 1974, 14 pp. (COM-74-50230)
- NESS 68 Dependence of Antenna Temperature on the Polarization of Emitted Radiation for a Scanning Microwave Radiometer. Norman C. Grody, January 1974, 11 pp. (COM-74-50431/AS)
- NESS 69 An Evaluation of May 1971 Satellite-Derived Sea Surface Temperatures for the Southern Hemisphere. P. Krishna Rao, April 1974, 13 pp. (COM-74-50643/AS)
- NESS 70 Compatibility of Low-Cloud Vectors and Rawins for Synoptic Scale Analysis. L. F. Hubert and L. F. Whitney, Jr., October 1974, 26 pp. (COM-75-50065/AS)
- NESS 71 An Intercomparison of Meteorological Parameters Derived From Radiosonde and Satellite Vertical Temperature Cross Sections. W. L. Smith and H. M. Woolf, November 1974, 13 pp. (COM-75-10432/AS)
- NESS 72 An Intercomparison of Radiosonde and Satellite-Derived Cross Sections During the AMTEX. W. C. Shen, W. L. Smith, and H. M. Woolf, February 1975, 18 pp. (COM-75-10439/AS)
- NESS 73 Evaluation of a Balanced 300-mb Height Analysis as a Reference Level for Satellite-Derived soundings. Albert Thomasell, Jr., December 1975, 25 pp.
- NESS 74 On the Estimation of Areal Windspeed Distribution in Tropical Cyclones With the Use of Satellite Data. Andrew Timchalk, August 1976, 41 pp.



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